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Virtual labs in life sciences education: A case study of grade 10 learners in selected South African rural schools

Mbalenhle Ngema [1], Abraham Motlhabane [1*]

[1] University of South Africa, Pretoria, SOUTH AFRICA

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Abstract

This study investigated the effectiveness of virtual reality lab activities in enhancing grade 10 learners' understanding of life sciences concepts and science process skills. A quasi-experimental design was employed, with a control group using traditional teaching methods and an experimental group using virtual reality lab activities. The results showed significant improvements in the experimental group's understanding of life sciences concepts and science process skills, including making observations, interpretation, measurement, recording data, and planning an investigation. The virtual reality lab activities were found to be effective in enhancing learners' understanding and skills, with significant differences observed between the control and experimental groups. The study's findings suggest that virtual reality lab activities can be a valuable tool for teaching life sciences and promoting science process skills and have implications for the integration of technology in science education.

Keywords: virtual reality, virtual labs, life sciences, science process skills, technology integration, life sciences concepts

INTRODUCTION

The advent of the 21st century and the Fourth Industrial Revolution has precipitated a pressing need for continuous adaptation and innovation in response to emerging challenges (Berg et al., 2021). In this context, science education plays a pivotal role in equipping learners with the requisite skills to navigate the complexities of the modern era. By fostering a deep understanding of scientific theories, practices, and innovations, science education makes a significant contribution to economic growth and development (Siayah & Setiawan, 2020). Moreover, science education empowers learners to apply their knowledge to address pressing technical, environmental, and human-related problems, thereby driving sustainable progress and innovation.

Within the South African basic education system, science education is delivered through a range of subjects, including life sciences. Each subject is guided by a distinct curriculum, which is overseen by the curriculum and assessment policy statement (CAPS) (Department of Basic Education [DBE], 2011). Notably, the life sciences CAPS document articulates three core curriculum goals, with the second goal emphasizing the importance of hands-on scientific inquiry and investigation. Furthermore, the CAPS document highlights the need for adequate workspace and equipment for learners to conduct investigations, highlighting the significance of practical learning experiences. In cases where resources are limited, teachers are encouraged to utilize improvised laboratory equipment, which involves creatively repurposing readily available materials or existing tools to facilitate scientific exploration (Ndihokubwayo et al., 2019). This adaptive approach to laboratory equipment reflects the resourcefulness and ingenuity required in science education.

The CAPS not only outlines the curriculum goals but also delineates the assessment requirements for life sciences, stipulating that practical work is a compulsory component of the subject (DBE, 2011). Specifically, the CAPS document mandates a formal task and practical exam as part of the assessment framework. However, a critical examination of the CAPS document reveals a notable inconsistency. While the document

✉ mbalenhlengema@gmail.com ✉ motlhat@unisa.ac.za **(*Correspondence)**

Contribution to the literature

- This study extends the existing body of research on the utilization of virtual reality labs in science education, specifically within the South African context.
- It addresses a critical gap in the literature by exploring the potential of virtual reality labs to enhance life sciences education in resource-constrained rural schools.
- The authors of this study contribute to the ongoing discussion on leveraging technology to address inequalities in science education.

acknowledges the possibility of improvising materials, the practical component for grade 10 is assessed through externally set papers that exclusively utilize real science laboratory materials, rather than improvised materials (DBE, 2011). This disparity may potentially disadvantage learners who have relied on improvised materials during teaching and learning, as they may struggle to recognize and apply their knowledge in the context of real laboratory materials presented in the assessment questions. This highlights a critical need for alignment between teaching, learning, and assessment practices in life sciences education.

Compounding the compulsory nature of the life sciences practical component, researchers such as Penn and Ramnarain (2019a) assert that experimental inquiry plays a pivotal role in concretizing abstract scientific concepts, thereby enhancing understanding and learning outcomes in science education. This argument posits that hands-on engagement with materials and phenomena in the laboratory setting is essential for learners to develop a deeper understanding of abstract scientific concepts. In other words, the act of conducting experiments serves as a critical catalyst for solidifying learners' grasp of these complex concepts, facilitating a more comprehensive understanding of scientific principles. By extension, this highlights the imperative need for educators to prioritize practical learning experiences in science education, fostering a more immersive and effective learning environment.

Furthermore, Barrow et al. (2019) highlight the complexity of life sciences as a subject, which necessitates a profound understanding of life processes at the molecular level and the ability to visualize abstract molecular and subcellular processes. Building on this notion, Penn and Ramnarain's (2019a) argument regarding the pivotal role of experimental inquiry in concretizing abstract scientific concepts gains significant traction. Considering these perspectives, the omission of the practical component in life sciences education may have far-reaching consequences, including the failure to effectively concretize the abstract aspects of the subject. This, in turn, may hinder learners' ability to fully comprehend certain concepts and develop their science process skills, thereby compromising the overall efficacy of life sciences education.

Research conducted in South Africa and globally highlight the significant hurdles in delivering science practical components, including inadequate laboratory infrastructure and insufficient timetable allocation for practical lessons (Saputra et al., 2021). In response to these challenges, scholars such as Fakorede (2020), Rahmadani et al. (2021), and Rivas et al. (2020) have identified virtual reality labs as a promising solution for teaching science practical lessons in resource-constrained settings. This innovative approach has the potential to bridge the gap in laboratory resources, providing learners with immersive and interactive learning experiences that foster deeper understanding and engagement with scientific concepts.

The scholarly works of Elmqaddem (2019) shed light on the integration of virtual reality labs in classroom settings, yielding a number of benefits. Notably, researchers attribute these advantages to the technology's capacity to simplify abstract scientific concepts, rendering them more accessible and comprehensible to learners (Elmqaddem, 2019). Furthermore, the virtual reality lab enables the visualization and experimentation of complex concepts that may be impractical or impossible to replicate in real-life settings, thereby expanding the boundaries of scientific inquiry and exploration (Lisborg, 2021). This innovative approach has the potential to revolutionize science education by providing immersive and interactive learning experiences that foster deeper understanding and engagement with scientific principles.

The virtual reality lab offers an array of advantages, including cost-effectiveness, which is a significant benefit compared to traditional laboratories (Lamb et al., 2020). Moreover, virtual reality labs demonstrate flexibility and accessibility across various interfaces, including smartphones, which are ubiquitous among learners, thereby promoting equitable access to scientific inquiry (Lamb et al., 2020). Additionally, virtual reality labs provide a secure and controlled environment for learners to conduct experiments, mitigating potential risks and hazards (Lisborg, 2021). This, in turn, fosters enhanced learner engagement, motivation, and overall academic achievement (Elmqaddem, 2019). By leveraging virtual reality labs, educators can create immersive and interactive learning experiences that cater to diverse learning styles and needs.

Several studies have investigated the efficacy of virtual reality labs as a tool for practical work in various educational contexts worldwide, such as the research conducted by Aliyu and Talib (2019) in Nigerian secondary schools and Aljuhani et al. (2018) in Saudi Arabian middle schools. However, a significant research gap exists regarding the application of virtual reality labs in South African educational settings, particularly with regards to its impact on the understanding of grade 10 life sciences concepts and the enhancement of science process skills. The study aims to contribute to the ongoing discourse on the utilization of virtual reality labs in high school science education, with a specific focus on life sciences. Furthermore, this research seeks to inform and potentially influence the design of the South African education curriculum and policies, thereby bridging the gap between innovative technologies and pedagogical practices.

METHODOLOGY

In alignment with established research conventions (Muijs, 2022), a quantitative research design was selected as the research methodology. This approach was motivated by the need to generate quantifiable and empirical data that could reveal the complex relationships between the two key variables under scrutiny (Williams et al., 2022). Specifically, these variables encompassed the enhancement of science process skills and the understanding of life sciences concepts, which constituted the core focus of the research inquiry and informed the development of the research questions.

In pursuit of the study's aim, which was to examine the impact of integrating virtual reality labs on grade 10 learners' understanding of life sciences concepts and science process skills, a quasi-experimental design was employed. Specifically, the non-equivalent control group design, utilizing the pretest-posttest approach (Orluwene & Ajala, 2020), was selected to investigate the causal relationship between the virtual reality lab (independent variable) and the enhancement of learners' understanding of life sciences concepts and science process skills (dependent variables). This design enabled the comparison of data from experimental and control groups across five distinct schools, providing a framework for quantifying the relationship between the two variables. By leveraging this design, the study aimed to explain the extent to which the virtual reality lab impacted on the enhancement of life sciences concepts and science process skills, both within and between the experimental and control groups.

Research Site

The motivation for selecting rural schools as research sites was the observation of the resource constraints in the uMkhanyakude District of education, which significantly impacts the implementation of the science curriculum, particularly the practical component. The definition of rural schools was informed by the rural education policy of the South African DBE (2017), which categorizes rural schools into three distinct categories. The first category encompasses location-specific factors, including isolation, remoteness, and dispersed settlements, often situated on government, communal, or private land (DBE, 2017). The second category comprises school-phase-specific factors, such as social and economic deprivation, poverty, distance from services and facilities, and the physical and cultural environment, which collectively impact the size and functionality of the school (DBE, 2017). The third category involves the application of multi-derivational indices, developed by statistics South Africa, to categorize public schools in rural areas, including those in Limpopo and the Eastern Cape (DBE, 2017).

The uMkhanyakude District of education, situated in the far northern region of KwaZulu-Natal (KZN). This district is not only one of the most rural in KZN but also faces significant infrastructural deficits, with numerous areas lacking access to basic amenities such as water and electricity. Furthermore, traditional leaders continue to play a significant role in governance, highlighting the district's rich cultural heritage. Comprising three circuits, uMkhanyakude District's Ingwavuma circuit was selected as the research site, with a focus on secondary schools within Mbabane ward. This context provides a unique opportunity to investigate the impact of resource constraints on science education in a rural and impoverished setting.

The five selected schools align with the rural education policy of the DBE's (2011) categorization, exhibiting characteristics that highlight the complexities of rural education. Notably, all five schools had access to electricity, but lacked science laboratories, a critical resource for science education. Three of the schools were classified as small, due to their remote locations, far from major roads and commercial areas, which limited their accessibility and potential for growth. In contrast, the two schools were large and overcrowded, situated in more accessible areas, but struggling with inadequate infrastructure, resulting in congested learning environments. This context sets the stage for the research, highlighting the challenges of rural education and the need for innovative solutions to address the disparities in resource allocation and infrastructure.

Population and Sampling

The research focused on grade 10 life sciences learners from the uMkhanyakude District of Education in KZN Province. The participants were purposefully selected based on specific criteria: they had to be enrolled in grade 10 at a secondary school within the uMkhanyakude District of education. This sampling strategy ensured a targeted and relevant sample, allowing for an in-depth exploration of the research questions and phenomena under investigation.

Table 1. Distribution of grade 10 life sciences learners across selected schools

School	Number of learners		N
	Control group	Experimental group	
A	22	28	50
B	21	25	38
C	44	51	95
D	39	43	82
E	23	26	47

A purposeful sampling strategy was employed to select the district, circuit, ward, and schools, acknowledging the need for a targeted approach given the resource and time constraints (Campbell et al., 2020). The uMkhanyakude District, comprising 165 secondary schools, presented a vast and diverse population.

Table 1 presents the distribution of grade 10 life sciences learners across the five selected schools, with a total of 312 learners participating in the study. The control and experimental groups are denoted by N, indicating the number of learners in each group.

Table 1 presents the distribution of grade 10 life sciences learners across five selected high schools, denoted by pseudonym A-pseudonym E. The initial sample comprised 322 learners, divided into a control group (N = 149) and an experimental group (N = 173). However, learner attrition occurred during the study, resulting in a total of 10 dropouts (6 from the control group and 4 from the experimental group). Consequently, the final analysis was based on a sample of 312 learners (control group: N = 143; experimental group: N = 169) from the five participating schools.

The allocation of grade 10 life sciences learners from the five selected schools to either the experimental or control group was accomplished through non-randomization, a strategy employed in response to the researcher's contextual constraints (Schmidt, 2017). In this instance, non-randomization was necessitated by the pre-existing allocation of learners to science classes within their respective schools, rendering randomization unfeasible. This approach enabled the researcher to adapt to the existing school structure, ensuring a more pragmatic and contextually grounded investigation.

This involved labeling two pieces of paper as group A and group B and having one grade 10 life sciences learner from each of the two classes select a piece of paper. The class of the learner who chose group A constituted the control group, while the class of the learner who chose group B formed the experimental group.

To facilitate identification and tracking of learners across the five schools, a numerical coding system was implemented. Each of the 312 participants was assigned a unique number (1-312). In each school, the number of grade 10 life sciences learners was determined, and corresponding numbers were written on pieces of paper and placed in a bowl. Learners then selected a number in sequence, starting from school A (numbers 1-50) to school E (numbers 265-312). This process ensured a systematic and organized approach to participant identification, enabling efficient data collection and analysis.

A unique identification system was employed to label each grade 10 life sciences learner, combining the selected number with the corresponding group letter (A or B). This dual-identifier system ensured efficient data organization and tracking throughout the study. For instance, a learner who chose the number 1 and was assigned to the experimental group was identified as 1B, while a learner who selected the same number but belonged to the control group was labeled as 1A. This systematic approach enabled accurate and efficient data management, facilitating the analysis of the pre-tests, and post-tests submitted by the learners.

Data Collection

To determine the impact of the independent variable (virtual reality lab versus traditional method) on two dependent variables (science process skills and conceptual understanding), a pre-/post-test design was employed. This approach enabled the measurement of grade 10 learners' science process skills and conceptual understanding related to the action of salivary amylase on starch, both before and after the intervention (Alam, 2019). The pre-test, administered prior to the practical activity, established a baseline understanding of learners' skills and knowledge (Alam, 2019). In contrast, the post-test, administered subsequent to the practical activity, allowed for a comparative analysis with the pre-test results, thereby determining the effectiveness of the practical activity in enhancing learners' science process skills and conceptual understanding.

The test administration process was conducted in two phases, with the initial phase involving the pre-test, which was administered to all participating learners one week prior to the practical activity. This was intentional, aimed at mitigating the potential effects of the pre-test on the treatment outcomes (Rogers & Revesz, 2019). The second phase involved the post-test, which was administered immediately following the practical activity. Both the pre- and post-tests were administered face-to-face, utilizing traditional pen and paper methods, with each learner completing the test individually. The duration of both tests was 45 minutes, after which all test scripts were collected from the learners. This procedure was rigorously followed across all five selected schools on separate days, ensuring consistency.

The initial visit to each of the five schools entailed the strategic allocation of grade 10 life sciences learners into control and experimental groups. In order not to disturb the school activities, the pre-test was conducted during an extramural activity, where learners from both groups were assembled in a single hall, simultaneously completing the pre-test under the researcher's supervision. Upon completion, all test scripts were collected from learners.

The second visit, occurring one week after the pre-test administration, involved the implementation of the practical activity with the experimental group, utilizing the desktop-based virtual reality lab. This enabled the researcher to assess the impact of the intervention on the experimental group.

The initial step involved the expert setup of the virtual reality lab by a technician provided by the company from which the laptops were rented. Following the successful establishment of the lab, each learner was assigned a laptop, and the session commenced with a 30-minute orientation on navigating the virtual reality lab. This introductory phase was aimed to familiarize learners with the innovative technology and facilitate a seamless learning experience.

To ensure a comprehensive understanding of the virtual lab, learners were encouraged to pose questions during the orientation session, fostering a clarifying and interactive learning environment. Subsequently, the experimental procedure was explained step-by-step over a 30-minute period, providing learners with essential prior knowledge to conduct the experiment successfully. By allowing learners to work individually, they were empowered to engage with the learning material at their own pace, promoting autonomy and self-directed learning. Following the explanation, learners were given 30 minutes to complete the practical activity independently, with the freedom to inquire about any unclear concepts. This instructional approach aligns with the experiential method, where learners navigate hands-on experiences firsthand, supported by a facilitator-teacher. Notably, learners in the experimental group had access to a multifaceted learning ecosystem, comprising 3D simulations, animations, text, and the researcher's guidance, to address any questions or challenges they encountered during the practical activity.

Throughout the practical activity, the researcher conducted observational assessments of learners' engagement with the virtual reality lab, noting their navigation and interaction with the simulated environment. Upon completion of the 30-minute practical activity, learners were administered a post-test, which they completed within a 45-minute time frame.

The third visit, occurring a week after the pre-test administration, involved the implementation of the practical activity with the control group, utilizing the traditional teaching method. This approach entailed disseminating handouts containing the procedural guidelines for the practical activity, followed by a 30-minute explanatory session, during which learners were encouraged to pose questions to clarify their understanding. Notably, learners in the control group had limited resources, relying solely on the researcher's guidance and textbooks to facilitate their comprehension of the practical activity. Subsequent to the 30-minute explanation, learners completed a post-test within a 45-minute time frame.

Upon completion of the data collection process across all five selected schools, learners from the control group were afforded the opportunity to engage with the virtual reality lab, mirroring the experience of the experimental group. This design decision ensured that the control group learners could also partake in the practical activity using the interactive virtual reality lab, thereby equalizing their exposure to the innovative technology. By postponing this experience until after data collection, potential contamination of the control group's results was effectively mitigated. By providing control group learners with equivalent virtual reality lab experience, the researcher aimed to promote equity and parity in their exposure to technology, further ethically enriching the study's methodological robustness.

Data Analysis

The data were entered into Excel, assigning a score of 1 for correct responses and 0 for incorrect ones (Taherdoost, 2022). Each individual's test scores were recorded, and data from the experimental and control groups were stored in separate Excel spreadsheets. The pre- and post-test data were then transferred to SPSS for analysis.

The first step of analysis involved a normality test to determine if the mean could represent the data (Mishra et al., 2019). The Kolmogorov-Smirnov test was used to determine data distribution, assuming normally distributed data with a p-value greater than 0.05 (Aslam, 2019). A p-value less than 0.05 indicated non-normal distribution (Jowkar et al., 2020).

The second step was a homogeneity test using Levene's test to determine variance equivalence between the control and experimental groups (Ahammed et al., 2021). A p-value greater than 0.05 indicated equivalent variances, while a p-value less than 0.05 indicated non-equivalent variances (Ramadhani et al., 2020).

As the data satisfied normal distribution and homogeneity conditions, parametric tests were used for analysis (Gerald, 2018). Despite non-normal distribution and variance, a t-test was used due to the large sample size (Hafner, 2021). Paired and independent t-tests were employed to compare means between the control and experimental groups (Mishra et al., 2019). The paired t-test assessed the effect of the virtual reality lab on concept understanding and science process skills by comparing pre- and post-test scores (Guetterman, 2019).

The independent t-test determined if differences were due to the treatment (Guetterman, 2019).

Four paired t-tests and two independent t-tests were performed on pre- and post-test data to determine the effect of the virtual reality lab on life science concept comprehension and science process skills. The analyses utilized total scores and scores for each question category. The results were displayed in tables with means, standard deviations, and p-values. The p-value determined whether to accept or reject the null hypothesis (Krueger & Heck, 2019).

Validity

To establish the causal effect of different experimental methods on the investigated variables, internal validity was ensured by mitigating associated threats (Fabrigar et al., 2020). The researcher minimized threats within their control, including the history effect (Mara & Peugh, 2020) by collecting data four weeks before the topic's formal introduction into the school curriculum. Maturation effects (Flannelly et al., 2018) were limited by considering the length and time required for data collection, ensuring instruments didn't exceed 40 questions and data collection didn't exceed two hours.

Testing effects (Flannelly et al., 2018) were mitigated by not administering test corrections between pre- and post-tests and administering the post-test one week after the pre-test. Instrumentation threats (Flannelly et al., 2018) were decreased by using the same equipment, identical pre- and post-test questions, and having the same researcher handle the entire data collection process. Experimenter effects (Białowąs, 2021) were minimized by the researcher's neutral attire, language, and consistent behavior across all five schools. Statistical regression threats (Białowąs, 2021) were limited by conducting the study with grade 10 learners at the beginning of the year, before exposure to the practical activity content. Selection biases (Baldwin, 2018) were mitigated by adopting appropriate sampling methods and allocating participants to control and experimental groups.

Reliability

Reliability, a crucial aspect of research, refers to the consistency of measurements obtained under uniform conditions using the same instrument (Sürücü & Maslakci, 2020). It encompasses not only the data collection instrument's consistency but also the resulting data and the appropriateness of research techniques (Coleman, 2019). To ensure reliability, consistent data collection procedures were employed across all five selected schools.

Given the single administration of each instrument by a sole researcher, internal consistency testing was employed to establish the reliability of the pre- and post-test data (Marcial & Launer, 2021). Internal consistency reliability measures were used to verify that participant responses were not random or falsified (Anselmi et al., 2019). Cronbach's alpha test, conducted using SPSS, determined the internal consistency of pre- and post-test data (Story & Tait, 2019). Cronbach's alpha coefficients indicate excellent (≥ 0.9), good (≥ 0.8), acceptable (≥ 0.7), questionable (≥ 0.6), poor (≥ 0.5), or unacceptable (< 0.5) internal consistency (Marcial & Launer, 2021).

Table 2. Cronbach's alpha (α) coefficients for the experimental group's pre- and post-test data

Dimension	Question numbers	Pre-test α	Post-test α
Science concepts	1-5	0.822 (excellent)	0.721 (good)
Making observations	6-8	0.783 (good)	0.728 (good)
Interpretation	9-11	0.796 (excellent)	0.775 (good)
Measurement	12-14	0.789 (good)	0.724 (good)
Recording data	15-17	0.756 (acceptable)	0.816 (excellent)
Planning an investigation	17-20	0.717 (acceptable)	0.768 (good)

Table 2 display the Cronbach's alpha coefficients for pre- and post-test

RESULTS

This study investigated two null hypotheses, each accompanied by a corresponding alternative hypothesis:

1. Null hypothesis (H0a). The integration of the virtual reality lab will have no significant effect on enhancing grade 10 learners' comprehension of life sciences concepts.
   - Alternative hypothesis (H1a). The virtual reality lab will have a positive impact on enhancing grade 10 learners' understanding of life sciences concepts, suggesting a significant improvement in their conceptual knowledge.
2. Null hypothesis (H0b). The virtual reality lab will not contribute significantly to the development of grade 10 learners' science process skills.
   - Alternative hypothesis (H1b). The virtual reality lab will have a significant impact on enhancing grade 10 learners' science process skills, fostering improved scientific inquiry, critical thinking, and problem-solving abilities.

To examine the effect of the virtual reality lab and traditional method on the experimental and control groups, respectively, a t-test was employed (Guetterman, 2019). This involved comparing the mean pre- and post-test scores between the two groups to determine any significant differences. The degree of difference between the means was indicated by the p-value, which can be greater or lesser than 0.05 (Guetterman, 2019). A p-value greater than 0.05 suggests

Table 3. Paired t-test results of pre- and post-test total scores for the control group

Test type	Group	Sample size	Mean	Standard deviation	df	t-value	Significance (p)
Pre-test	Control	143	3.54	1.569	142	-19.183	< 0.001
Post-test			8.06	2.386			

Note. The paired t-test was used to compare the means of the pre- and post-test scores within the control group & a significance level of p < 0.001 indicates a significant difference between the means

Table 4. Paired t-test results of pre- and post-test total scores for the experimental group

Test type	Group	Sample size	Mean	Standard deviation	df	t-value	Significance (p)
Pre-test	Experimental	169	0.77	0.919	168	-77.561	< 0.001
Post-test			13.81	1.949			

Note. The paired t-test was used to compare the means of the pre- and post-test scores within the experimental group & a significance level of p < 0.001 indicates a significant difference between the means

no significant difference between the means, while a p-value less than 0.05 indicates a significant difference.

Two types of t-tests were used to analyze the pre- and post-test scores: paired t-tests and independent t-tests. Paired t-tests compared the means of participants within the same group (Gerald, 2018), examining changes in pre- and post-test scores within the experimental and control groups. The results are presented in tables. Independent t-tests, on the other hand, compared the means of samples from different groups (Gerald, 2018), determining whether changes in pre- and post-test scores were due to the practical activity using the prescribed method for each group. The results were used to accept or reject the null hypotheses of the study.

The results presented in **Table 3** reveal a statistically significant difference between the mean scores of the control group in the pre- and post-test, with a p-value of less than 0.001. Notably, the post-test mean score (8.06) significantly exceeded the pre-test mean score (3.54), indicating a substantial improvement in test scores after the practical activity using the traditional method. This finding suggests that the control group's performance significantly enhanced after engaging in practical activity.

A paired t-test was also conducted to examine the pre- and post-test total scores within the experimental group. This analysis aimed to determine whether a significant difference existed between the pre- and post-test scores after the practical activity. By comparing the scores within the experimental group, this analysis provided insight into the effectiveness of the virtual reality lab in enhancing the test scores of the experimental group.

The results presented in **Table 4** reveal a statistically significant difference between the mean scores of the experimental group in the pre- and post-test, with a p-value of less than 0.001. This significant difference favors the post-test, indicating a substantial improvement in scores after the practical activity using the virtual reality lab.

A comparison of the results in **Table 3** and **Table 4** reveals a statistically significant difference between the pre- and post-test scores within both the control and experimental groups. Notably, the mean post-test scores exceeded the mean pre-test scores in both groups. While this suggests improvement in test scores, it is essential to investigate whether this improvement translates to enhanced understanding of concepts and process skills. To address this, a paired t-test was conducted to compare the mean scores of each question category within the control and experimental groups.

The fourth paired t-test analyzed the pre- and post-test scores of the control group for each question category, including science concepts, making observations, interpretation, measurement, recording data, and planning an investigation. The results, presented in **Table 5**, provide insight into changes in each question category, offering a more nuanced understanding of the improvements observed in the post-test scores.

The results presented in **Table 5** reveal statistically significant differences between the mean scores of the control group's pre- and post-test on questions related to making observations ($p < 0.001$), interpretation ($p < 0.001$), measurement ($p < 0.001$), recording data ($p < 0.001$), and planning an investigation ($p < 0.001$). All these results favor the post-test, indicating higher scores in the post-test compared to the pre-test. This suggests that engaging in the practical activity using the traditional method significantly enhanced the control group's science process skills in these areas.

In contrast, no significant difference was found between the mean scores of the control group's pre- and post-test on questions related to science concepts ($p = 0.848 > 0.05$), with the results favoring the pre-test. This indicates that the control group's understanding of science concepts did not improve after the practical activity using the traditional method.

A fifth paired t-test was conducted to examine the pre- and post-test scores of the experimental group for each question category, including science concepts, making observations, interpretation, measurement, recording data, and planning an investigation. The results, presented in **Table 6**, provide insight into

Table 5. Paired t-test results of pre- and post-test total scores for the control group by question category

Question category	Group	Test type	Mean	Standard deviation	df	t-value	Significance (p)
Science concepts (Q1-5)	Control	Pre-test	1.89	1.888	142	-0.192	< 0.001
		Post-test	1.85	1.680		0.192	
Making observations (Q6-8)		Pre-test	0.37	0.917		-7.793	
		Post-test	1.34	1.193		7.793	
Interpretation (Q9-11)		Pre-test	0.31	0.771		-9.706	
		Post-test	1.48	1.203		9.706	
Measurement (Q12-14)		Pre-test	0.19	0.605		-6.320	
		Post-test	0.82	1.085		6.320	
Recording data (Q15-17)		Pre-test	0.34	0.804		-10.436	
		Post-test	1.59	1.206		10.436	
Planning and investigation (Q17-20)		Pre-test	0.45	0.917		-4.463	

Note. The paired t-test was used to compare the means of the pre- and post-test scores within the control group for each question category & a significance level of $p < 0.001$ indicates a significant difference between the means

Table 6. Paired t-test results of pre- and post-test total scores for the experimental group by question category

Question category	Group	Test type	Mean	Standard deviation	df	t-value	Significance (p)
Science concepts (Q1-5)	Experimental	Pre-test	1.83	1.842	168	-6.732	< 0.001
		Post-test	3.18	1.652		6.732	
Making observations (Q6-8)		Pre-test	0.27	0.722		-14.021	
		Post-test	1.87	1.173		14.021	
Interpretation (Q9-11)		Pre-test	0.24	0.684		-14.099	
		Post-test	1.89	1.205		14.099	
Measurement (Q12-14)		Pre-test	0.15	0.556		-16.257	
		Post-test	1.80	1.183		16.257	
Recording data (Q15-17)		Pre-test	0.29	0.727		-14.987	
		Post-test	1.98	1.217		14.987	
Planning and investigation (Q17-20)		Pre-test	0.25	0.662		-21.716	

Note. The paired t-test was used to compare the means of the pre- and post-test scores within the experimental group for each question category & a significance level of $p < 0.001$ indicates a significant difference between the means

changes in each question category, offering a more nuanced understanding of the improvements observed in the post-test scores.

The results presented in **Table 6** reveal statistically significant differences between the mean scores of the control group's pre- and post-test on questions related to science concepts ($p < 0.001$), making observations ($p < 0.001$), interpretation ($p < 0.001$), measurement ($p < 0.001$), recording data ($p < 0.001$), and planning an investigation ($p < 0.001$). The results favor the post-test, with the most pronounced difference observed in science concepts. This suggests that engaging in the practical activity using the virtual reality lab significantly enhanced the control group's understanding of science concepts and science process skills across various categories.

A comparison of the results in **Table 5** and **Table 6** reveals changes in the pre- and post-test total scores within the control and experimental groups, respectively. Furthermore, the results in **Table 5** and **Table 6** show changes in the pre- and post-test scores of each question category within the control and experimental groups, with the exception of science concepts, which showed a higher pre-test mean score than post-test mean score in the control group.

To investigate whether the improvement in scores was attributed to the prescribed method for each group and to test the study's hypotheses, an independent t-test analysis was conducted on the total post-test scores of the control and experimental groups for each question category (see **Table 7**). This analysis aimed to determine if the virtual reality lab and traditional method had a significant impact on the post-test scores of the experimental and control groups, respectively.

The independent t-test results revealed a significant difference in post-test scores between the control and experimental groups in the science concepts category ($p < 0.001$), favoring the experimental group. This led to the rejection of the null hypothesis (H0a) and acceptance of the alternative hypothesis (H1a), indicating that the virtual reality lab effectively enhanced grade 10 learners' understanding of life sciences concepts related to enzyme activity and temperature. To further investigate, the null hypothesis (H0b) and alternative hypothesis (H1b) were tested, examining the impact of the virtual reality lab on science process skills. The independent t-test results showed significant differences in post-test scores between the control and experimental groups in the categories of making observations ($p < 0.001$), interpretation ($p < 0.001$), measurement ($p < 0.001$),

Table 7. Independent t-test results of post-test scores for each question category between control and experimental groups

Question category	Group	Test type	Mean	Standard deviation	df	t-value	Significance (p)
Science concepts (Q1-5)	Control	Pre-test	1.85	1.680	299	7.028	< 0.001
	Experimental	Post-test	3.18	1.652			
Making observations (Q6-8)	Control	Pre-test	1.34	0.193		3.918	
	Experimental	Post-test	1.87	1.173			
Interpretation (Q9-11)	Control	Pre-test	1.48	1.203	301	3.054	0.002
	Experimental	Post-test	1.89	1.205			
Measurement (Q12-14)	Control	Pre-test	0.82	1.085	307	7.630	< 0.001
	Experimental	Post-test	1.80	1.183			
Recording data (Q15-17)	Control	Pre-test	1.59	1.217	302	2.818	0.005
	Experimental	Post-test	1.98	1.206			
Planning and investigation (Q17-20)	Control	Post-test	0.99	1.216	287	9.519	< 0.001

Note. The paired t-test was used to compare the means of the pre- and post-test scores of each question category between the control and experimental groups & a significance level of $p < 0.001$ indicates a significant difference between the means

recording data ($p < 0.001$), and planning an investigation ($p < 0.001$), all favoring the experimental group. These results led to the rejection of the null hypothesis (H0b) and acceptance of the alternative hypothesis (H1b), indicating that the virtual reality lab effectively enhanced grade 10 learners' science process skills.

DISCUSSION

This study was prompted by the pressing issue of inadequate science laboratory facilities in rural schools within the uMkhanyakude District. However, this challenge is not unique to this region, as numerous South African schools face similar limitations (National Education Infrastructure Management System [NEIMS], 2021). Research has consistently highlighted the absence of science laboratories as a nationwide obstacle, hindering the incorporation of practical activities in science education (Gudyanga & Jita, 2019; Penn & Ramnarain, 2019b). In response, virtual reality labs have been identified as a potential solution for areas where traditional science laboratories are lacking (Penn & Ramnarain, 2019b). The importance of hands-on experimentation in fostering a comprehensive understanding of scientific concepts and developing essential science process skills is highlighted by Ghergulescu et al. (2019).

According to constructivist learning theory, active learning through experiments plays a crucial role in the construction and understanding of science concepts (Umida et al., 2020). This highlight the importance of hands-on experimentation in science education, as the absence of experiments may deprive learners of the opportunity to fully comprehend scientific concepts. In the context of South African rural schools, the lack of practical activities poses a significant challenge to effective understanding of life sciences, as concepts may remain abstract and disconnected from real-world applications. Moreover, this shortage of practical experiences hinders rural schools from fulfilling curriculum requirements, as practical exams are a mandatory component of life sciences assessment (DBE, 2011). This study contributes to the ongoing discussion on leveraging virtual reality labs in science education to address the scarcity of high school science labs, with a particular focus on South Africa's life sciences. The findings of this study potentially contribute to the broader discourse on life sciences teaching and learning, curriculum design, and implementation in South Africa. Specifically, this research provides new insights into the application of virtual reality labs as a viable solution to overcome the scarcity of high school science labs in South African rural schools, informing curriculum design, implementation, and teaching practices in life sciences.

CONCLUSION

This study demonstrated the effectiveness of virtual reality lab activities in enhancing grade 10 learners' understanding of life sciences concepts and science process skills. The findings support the use of virtual reality technology as a valuable tool for teaching and learning in science education. The results highlight the potential of virtual reality lab activities to improve learners' understanding of complex scientific concepts and develop essential science process skills. The study's findings have implications for science education, suggesting that virtual reality technology can be integrated into teaching practices to enhance learner engagement, motivation, and understanding. The use of virtual reality lab activities can also help address challenges such as limited resources, safety concerns, and difficulties in replicating real-world environments.

Future research can build on this study by exploring the use of virtual reality technology in other scientific disciplines and educational contexts. Additionally, investigations into the long-term impact of virtual reality lab activities on learners' understanding and retention of scientific concepts and skills would be valuable.

Overall, this study demonstrates the potential of virtual reality lab activities to enhance science education and provides a foundation for further research and innovation in this area.

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REFERENCES

Ahammed, B., Jahan, N., Seddeque, A., Hossain, M. T., Shovo, T. E. A., Khan, B., Mamun, M. A., & Islam, M. N. (2021). Exploring the association between mental health and subjective sleep quality during the COVID-19 pandemic among Bangladeshi university students. *Heliyon, 7*(5), Article e07082. https://doi.org/10.1016/j.heliyon.2021.e07082

Alam, T. G. M. R. (2019). Comparative analysis between pre-test/post-test model and post-test-only model in achieving the learning outcomes. *Pakistan Journal of Ophthalmology, 35*(1). https://doi.org/10.36351/pjo.v35i1.855

Aliyu, F., & Talib, C. A. (2019). Virtual chemistry laboratory: A panacea to problems of conducting chemistry practical at science secondary schools in Nigeria. *International Journal of Engineering and Advanced Technology, 8*(5), 544-549. https://doi.org/10.35940/ijeat.e1079.0585c19

Aljuhani, K., Sonbul, M., Althabiti, M., & Meccawy, M. (2018). Creating a virtual science lab (VSL): The adoption of virtual labs in Saudi schools. *Smart Learning Environments, 5*(1). https://doi.org/10.1186/s40561-018-0067-9

Anselmi, P., Colledani, D., & Robusto, E. (2019). A comparison of classical and modern measures of internal consistency. *Frontiers in Psychology, 10*. https://doi.org/10.3389/fpsyg.2019.02714

Aslam, M. (2019). Introducing Kolmogorov-Smirnov tests under uncertainty: An application to radioactive data. *ACS Omega, 5*(1), 914-917. https://doi.org/10.1021/acsomega.9b03940

Baldwin, L. (2018). Internal and external validity and threats to validity. In L. Baldwin (Ed.), *Research concepts for the practitioner of educational leadership* (pp. 31-36). Brill Sense. https://doi.org/10.1163/9789004365155_007

Barrow, J., Forker, C., Sands, A., O'Hare, D., & Hurst, W. (2019). *Augmented reality for enhancing life science education* [Paper presentation]. *The 4th International Conference on Applications and Systems of Visual Paradigms*.

Berg, T. B., Achiam, M., Poulsen, K. M., Sanderhoff, L. B., & Tøttrup, A. P. (2021). The role and value of out-of-school environments in science education for 21st century skills. *Frontiers in Education, 6*. https://doi.org/10.3389/feduc.2021.674541

Białowąs, S. (2021). *Experimental design and biometric research. Toward innovations*. PUEB Press. https://doi.org/10.18559/978-83-8211-079-1/I1

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples. *Journal of Research in Nursing, 25*(8), 652-661. https://doi.org/10.1177/1744987120927206

Coleman, S. K., & Smith, C. L. (2019). Evaluating the benefits of virtual training for bioscience students. *Higher Education Pedagogies, 4*(1), 287-299. https://doi.org/10.1080/23752696.2019.1599689

DBE. (2011). Curriculum and assessment policy statement. Grades 10-12 life sciences. *Department of Basic Education*. https://www.education.gov.za/Portals/0/CD/National%20Curriculum%20Statements%20and%20Vocational/CAPS%20FET%20_%20LIFE%20SCIENCES%20_%20GR%2010-12%20Web_2636.pdf

DBE. (2017). Rural education draft policy. *Department of Basic Education*. https://www.education.gov.za/Portals/0/Documents/Policies/Draft%20Policy%20on%20Rural%20Education%200218.pdf?ver=2018-02-09-105713-287

Elmqaddem, N. (2019). Augmented reality and virtual reality in education. Myth or reality? *International Journal of Emerging Technologies in Learning, 14*(3). https://doi.org/10.3991/ijet.v14i03.9289

Fabrigar, L. R., Wegener, D. T., & Petty, R. E. (2020). A validity-based framework for understanding replication in psychology. *Personality and Social Psychology Review, 24*(4), 316-344. https://doi.org/10.1177/1088868320931366

Fakorede, S. O. A. (2020). Effect of virtual laboratory on students learning outcomes in automobile technology. *International Journal of Innovative Technology Integration in Education, 4*(1), 77-87.

Flannelly, K. J., Flannelly, L. T., & Jankowski, K. R. B. (2018). Threats to the internal validity of experimental and quasi-experimental research in healthcare. *Journal of Health Care Chaplaincy, 24*(3), 107-130. https://doi.org/10.1080/08854726.2017.1421019

Gerald, B. (2018). A brief review of independent, dependent and one sample t-test. *International Journal of Applied Mathematics and Theoretical Physics, 4*(2), Article 50. https://doi.org/10.11648/j.ijamtp.20180402.13

Ghergulescu, I., Moldovan, A. N., Muntean, C. H., & Muntean, G. M. (2019). Atomic structure Interactive personalised virtual lab: Results from an evaluation study in secondary schools. In *Proceedings of the CSEDU* (pp. 605-615). https://doi.org/10.5220/0007767806050615

Gudyanga, R., & Jita, L. C. (2019). Teachers' implementation of laboratory practicals in the South African physical sciences curriculum. *Issues in Educational Research, 29*(3), 715-731.

Guetterman, T. C. (2019). Basics of statistics for primary care research. *Family Medicine and Community Health, 7*(2), Article e000067. https://doi.org/10.1136/fmch-2018-000067

Hafner, C. (2021). Diversification in family firms: a systematic review of product and international diversification strategies. *Review of Managerial Science, 15*(3), 529-572. https://doi.org/10.1007/s11846-019-00352-5

Jowkar, Z., Masoumi, M., & Mahmoodian, H. (2020). Psychological stress and stressors among clinical dental students at Shiraz School of Dentistry, Iran. *Advances in Medical Education and Practice, 11*, 113-120. https://doi.org/10.2147/amep.s236758

Krueger, J. I., & Heck, P. R. (2019). Putting the p-value in its place. *The American Statistician, 73*(Sup1), 122-128. https://doi.org/10.1080/00031305.2018.1470033

Lamb, R., Lin, J., & Firestone, J. B. (2020). Virtual reality laboratories: A way forward for schools? *Eurasia Journal of Mathematics, Science and Technology Education, 16*(6), Article em1856. https://doi.org/10.29333/ejmste/8206

Lisborg, S. (2021). Virtual educational laboratories: Instructive or explorative learning? *DASTS, 12*(1), 19-49. https://doi.org/10.7146/stse.v12i1.135401

Mara, C. A., & Peugh, J. L. (2020). Validity of data collected from randomized behavioral clinical trials during the COVID-19 pandemic. *Journal of Pediatric Psychology, 45*(9), 971-976. https://doi.org/10.1093/jpepsy/jsaa078

Marcial, D., & Launer, M. (2021). Test-retest reliability and internal consistency of the survey questionnaire on digital trust in the workplace. *Solid State Technology, 64*(2), 4369-4381.

Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia, 22*(1), Article 67. https://doi.org/10.4103/aca.aca_157_18

Muijs, D. (2022). *Doing quantitative research in education with IBM SPSS statistics*. SAGE.

Ndihokubwayo, K., Uwamahoro, J., & Ndayambaje, I. (2019). An assessment of the impact of improvised versus conventional laboratory equipment on students' performance in thermal expansion. *African Journal of Educational Studies in Mathematics and Sciences, 15*(1), 135-140. https://doi.org/10.4314/ajesms.v15i1.11

NEIMS. (2021). *National education infrastructure management system report*. https://www.education.gov.za/Portals/0/Documents/Reports/NEIMS%20STANDARD%20REPORT%202021.pdf?ver=2021-05-20-094532-570

Orluwene, G. W., & Ajala, I. (2020). Determining research design and data analysis: Suggestions for navigating postgraduate research. In M. K. Y. Cross, G. M. Kibanja, & A. R. Mwesigye (Eds.), *Postgraduate research engagement in low resource setting* (pp. 115-128). IGI Global. R. Mwesigye (Eds.), Postgraduate research engagement in low resource setting (pp. 115-128). IGI Global. https://doi.org/10.4018/978-1-7998-0264-8.ch003

Penn, M., & Ramnarain, U. (2019a). A comparative analysis of virtual and traditional laboratory chemistry learning. *Perspectives in Education, 37*(2), 80-97. https://doi.org/10.18820/2519593x/pie.v37i2.6

Penn, M., & Ramnarain, U. (2019b). South African university students' attitudes towards chemistry learning in a virtually simulated learning environment. *Chemistry Education Research and Practice, 20*(4), 699-709. https://doi.org/10.1039/c9rp00014c

Rahmadani, N. F., Ariani, S. R. D., Mulyani, S., & Yunita, N. (2021). Chemistry teachers' perspectives on virtual STEM laboratories as learning media. In *Proceedings of the 6th International Seminar on Science Education* (pp. 627-633). Atlantis Press. https://doi.org/10.2991/assehr.k.210326.091

Ramadhani, R., Bina, N. S., Sihotang, S. F., Narpila, S. D., & Mazaly, M. R. (2020). Students' critical mathematical thinking abilities through flip-problem based learning model based on LMS-google classroom. *Journal of Physics: Conference Series, 1657*, Article 012025. https://doi.org/10.1088/1742-6596/1657/1/012025

Rivas, Y. C., Valdivieso, P. A. V., & Rodriguez, M. A. Y. (2020). Virtual reality and 21st century education. *International Research Journal of Management, IT and Social Sciences, 7*(1), 37-44. https://doi.org/10.21744/irjmis.v7n1.820

Rogers, J., & Revesz, A. (2019). Experimental and quasi-experimental designs. In J. McKinley, & H. Rose (Eds.), *The Routledge handbook of research methods in applied linguistics* (pp. 133-143). Routledge. https://doi.org/10.4324/9780367824471-12

Saputra, I. G. P. E., Harnipa, H., & Akhfar, M. (2021). Development of science learning device oriented guided inquiry with virtual laboratory to train science process skills of junior high school students in Kendari. *Jurnal Penelitian & Pengembangan Pendidikan Fisika, 7*(1), 13-22. https://doi.org/10.21009/1.07102

Schmidt, WP. 2017. Randomised and non-randomised studies to estimate the effect of community-level public health interventions: definitions and methodological considerations. *Emerging Themes in Epidemiology, 14*, Article 9. https://doi.org/10.1186/s12982-017-0063-5

Siayah, S., & Setiawan, A. R. (2020). A brief explanation of science education. *EdArXiv*. https://doi.org/10.35542/osf.io/2evn3

Story, D. A., & Tait, A. R. (2019). Survey research. *Anesthesiology, 130*(2), 192-202. https://doi.org/10.1097/aln.0000000000002436

Sürücü, L., & Maslakçi, A. (2020). Validity and reliability in quantitative research. *Business & Management Studies: An International Journal, 8*(3), 2694-2726. https://doi.org/10.15295/bmij.v8i3.1540

Taherdoost, H. (2022). Designing a questionnaire for a research paper: A comprehensive guide to design and develop an effective questionnaire. *Asian Journal of Managerial Science, 11*(1), 8-16. https://doi.org/10.51983/ajms-2022.11.1.3087

Umida, K., Dilora, A., & Umar, E. (2020). Constructivism in teaching and learning process. *European Journal of Research and Reflection in Educational Sciences, 8*(3), Article 134.

Williams, M., Wiggins, R., Vogt, W. P., & Vogt, P. R. (2022). *Beginning quantitative research*. SAGE. https://doi.org/10.4135/9781529682809

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