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Exploring the Integration of Virtual Laboratories in Science Education:
Insights From Rural Teachers in South Africa

Brian Shambare
https://orcid.org/0000-0002-4869-8407
Rhodes University, South Africa

Clement Simuja
https://orcid.org/0000-0002-0105-0013
Rhodes University, South Africa

ABSTRACT

The advantage of VLs lies in their capacity for simulating real-world lab experiences within a fully immersive digital environment, yet the uptake in rural schools in developing countries remains low. To understand this paradox, this study explores the perceptions of seven secondary school science teachers in a rural district in South Africa. Through a qualitative case-study methodology guided by the interpretive paradigm, this research adopts a phenomenological approach to gain insights into teachers' attitudes, understandings, and the factors influencing their acceptance or rejection of this technology. The Unified Theory of Acceptance and Use of Technology is employed as a theoretical framework. The study finds that despite potential educational benefits, the actual use of VLs is largely influenced by teacher perceptions and experiences, rooted in context-specific challenges. The findings reveal that teachers perceive VL as a beneficial and practical tool providing access to high-quality lab equipment necessary for student experiments, which could otherwise be cost-prohibitive.

KEYWORDS

Educational Technologies, Information and Communication Technology (ICT), Laboratory Experiments, Teacher Perceptions, Virtual Laboratory

Science teachers and researchers widely agree that hands-on experiments are fundamental for effective teaching and learning (Fernandez et al., 2023; Hodson, 2014; Hofstein & Lunetta, 2004). Consequently, developing students' scientific abilities, such as questioning, hypothesizing, observing, measuring, drawing conclusions, and formulating recommendations, relies heavily on their capacity to conduct practical experiments in laboratories (Chowdhury et al., 2019). Similarly, Gultepe and Kilic (2015) contend that students absorb scientific concepts more efficiently by engaging in tactile experiences, measurement tasks, chart generation, data recording, interpretation, and conclusion drawing. Furthermore, laboratory experiments provide a platform for constructing, verifying, reconstructing, and fortifying scientific understanding (Holmes et al., 2015). Consequently, well-designed laboratory experiments can potentially elevate students' cognitive abilities from basic to advanced thinking skills, enabling them to operate at various levels of Bloom's taxonomy, including analysis, synthesis, and evaluation.

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However, despite the acknowledged necessity of hands-on laboratory experimentation with tangible equipment and materials, many schools in developing nations like South Africa, particularly rural ones, frequently confront financial obstacles in procuring and sustaining laboratory infrastructure. As per UN Trade and Development (UNCTAD), developing countries are delineated through specific parameters, which evaluate low-income status based on the average annual income per capita over three years (below $745 annually). Additionally, assessing deficient human resources involves scrutinizing indicators such as educational enrolment rates and adult literacy levels. Moreover, economic susceptibility is gauged by factors such as geographical isolation, susceptibility to natural calamities, and a population size under 75 million (UNCTAD, 2021). South Africa meets all these criteria.

Moreover, rural areas in developing nations grapple with many challenges linked to deficient service provision. These hurdles encompass limited access to resources and job opportunities, substandard education quality, heightened poverty rates, and inadequate infrastructure, such as roads and other essential amenities (Cloke, 2006; Crumb et al., 2023; Novotný et al., 2015). Consequently, compared to well-equipped schools predominantly situated in urban settings, science education in rural schools encounters more intricate and distinct obstacles. At the heart of these issues lies a lack of service delivery, resulting in the lack or insufficiency of fundamental infrastructure—including science laboratories, classrooms, and libraries—in most rural educational institutions in developing nations. The absence or inadequacy of laboratory equipment predominantly contributes to subpar science instruction and learning experiences in these rural schools (Cicchinelli & Beesley, 2017; Murphy, 2022; Yue et al., 2018). This predicament is exacerbated by the chronic underfunding plaguing most rural schools, consequently undermining science education. Despite the ongoing efforts by governments and non-governmental organizations (NGOs) in developing countries to promote high-quality science education for all students, achieving this goal remains an elusive aspiration for many rural schools.

Given these challenging circumstances, exploring alternative laboratory platforms that enable students and teachers to conduct necessary experiments while meeting their curriculum objectives is imperative. With the widespread integration of technology across various domains, a notable uptake of new and innovative technologies has occurred in education. One such recent innovation in science education is the virtual lab (VL). Defined by Lestari and Supahar (2020) as a "simulated version of a traditional laboratory" (p. 23), a VL provides learners with virtual representations of actual laboratory instruments and equipment. In essence, a VL serves as a digital platform where teachers and students can engage in experiments using devices such as computers and smartphones, which feature virtual renditions of lab apparatuses and chemicals. Consequently, physical laboratory equipment and materials are transposed into computer software programs within the VL environment. Presently, numerous VL programs are available free of charge and do not necessitate access to a school's internet infrastructure—a particularly advantageous feature for rural schools.

The integration of interactive and innovative technologies such as VLs into science education is revolutionizing learning environments worldwide. This transformation presents an increasing potential to enhance students' comprehension of abstract concepts through authentic experiential learning that mirrors real-world laboratory experiences. Leveraging computer-simulated laboratory equipment that never requires replacement and chemical reactants that do not expire (Shambare et al., 2022), VL technology empowers teachers and students to conduct experiments within a fully immersive and interactive virtual setting (Aliyu & Talib, 2019). Furthermore, VLs facilitate the exploration of three-dimensional (3D) objects from multiple perspectives, including internal structures, right down to minuscule particles such as atomic structures (Kapilan et al., 2021).

Numerous studies have demonstrated that VLs can significantly enhance student learning outcomes. For instance, Shambare and Simuja's (2022) comprehensive literature review, comprising 32 empirical studies from 16 countries, revealed notable improvements in students' academic performance. Among the reviewed studies are those conducted in Malaysia by Oloruntegbe and Alam (2010), in Slovenia by Herga et al. (2014), in Italy by Pellas (2014), in the United States by Davenport et al. (2018), and in Turkey by Kapici et al. (2022). Similarly, research conducted in developing nations, such as Zimbabwe (Bhukuvhani et al., 2010), Lesotho (George & Kolobe, 2014), and Nigeria (Aliyu & Talib, 2019), has corroborated VLs' effectiveness in enhancing students' academic achievements. However, despite the myriad benefits of integrating VLs into teaching practices, their adoption remains limited in rural schools across most developing countries.

Hence, this study investigates teachers' perspectives and encounters regarding teaching with VLs in a developing nation. The key contributions of this research are as follows: (1) As an integral component of the broader body of research on VLs, our objective is to contribute to comprehending the factors that may facilitate or hinder the adoption of VLs in rural schools within developing countries. (2) Given that the concept of the VL is still in its nascent stage in most developing nations, we aim to initiate discussions on VLs among teachers and academics in similar contexts.

To fulfill our objectives, this paper is structured as follows: It begins with a literature review, followed by an exploration of the study's theoretical perspectives. Next, the methodology section outlines the research approach. Subsequently, we present and discuss the findings. The paper concludes with a summary, concluding remarks, and implications for further research.

LITERATURE SYNTHESIS

Rural Teaching Context

Rural science teaching in developing countries poses complex challenges unique to these settings. These difficulties often stem from limited socioeconomic resources, inadequate school facilities, and a scarcity of qualified teachers, particularly in key subjects like science (White & Downey, 2021). For instance, Assey et al. (2022) explored how various rural factors influence the quality of education in the Tabora region of rural Tanzania. Their research revealed that poverty at both the family and community levels has a detrimental impact on teaching quality.

In addition, Mtsi and Maphosa (2016) outlined various hurdles related to the absence of fundamental science teaching resources in rural South African schools. They emphasized that rural educators face the significant challenge of a dearth of science infrastructure, notably laboratories. Similarly, Ramnarain and Hlatswayo (2018) highlighted how resource deficiencies impede effective science teaching in many rural South African schools. Bantwini (2017) also observed that many rural schools lack adequate resources. His observations were grounded in questionnaire responses and science lesson observations conducted in rural schools within South Africa's Eastern Cape province. Similar findings are echoed in several other studies, including those by Ramnarain (2014), Tsakeni et al. (2019), and Shambare et al. (2022).

When examining the literature surrounding rural teaching environments, a multitude of challenges emerge. Firstly, rural areas often face political, social, and economic exclusion (Cloke, 2006; Sherman & Schafft, 2022). Consequently, secondary school teachers in rural settings find themselves marginalized, effectively sidelined from national discussions on education. Moreover, due to the curriculum's tendency to mirror urban teaching environments, rural secondary school teachers' unique needs are frequently neglected in policy formulation and implementation. Hence, this study explores how contextual factors affect teachers' reception of VLs. The research seeks to comprehend and elucidate the perceptions and experiences of life sciences secondary school teachers regarding VL integration in rural teaching settings.

Another significant challenge prevalent in rural areas of developing countries, which constitutes the backdrop of this research, is their dispersed geographical nature (Du Plessis & Mestry, 2019). Consequently, schools in rural regions are often situated far from students' residences. This geographical dispersion poses several challenges for students attending rural schools, including long travel distances, exposure to inadequate bridges and roads, and a lack of sufficient transportation options. The frequent impassability of roads during rainy days exacerbates these challenges, potentially causing students to miss classes and experiments. Furthermore, rural areas typically lack basic amenities, such as running water, sanitation facilities, electricity, and educational resources. The cumulative effect of these factors may significantly impede rural students' access to high-quality science education.

In addition, most rural schools in developing countries face a persistently high teacher turnover rate. These schools encounter difficulties recruiting and retaining qualified science teachers with the requisite experience and expertise (Hlalele & Mosia, 2020). Furthermore, once hired, science teachers often find themselves tasked with teaching multiple subjects across various grades while contending with high teacher-to-student ratios (Du Plessis & Mestry, 2019). Given rural areas' limited cultural and social opportunities, many secondary school science teachers may lack enthusiasm for working in such settings. Even those willing to work in rural schools often find the conditions discouraging, leading to a reluctance to remain for extended periods (Assey et al., 2022; Bantwini, 2017; Du Plessis & Mestry, 2019). Consequently, when competent teachers transfer from rural schools to urban areas, they leave behind many underqualified or unqualified teachers. Numerous studies examining teacher demographics in rural schools across developing countries corroborate this trend, revealing a significant presence of underqualified or unqualified teachers in the subjects they teach (Bantwini, 2017; White & Downey, 2021).

VLs in Developing Countries

Informed by the existing literature, integrating VLs into teaching offers several appealing benefits. For instance, Bogusevschi et al. (2020) discovered that the procurement and upkeep of state-of-the-art laboratory equipment can incur substantial costs in traditional hands-on practical sessions. For example, the Maryland State Department of Education in the United States allocated US$27,941,000 to renovate science laboratories in 77 secondary schools (OECD, 1999). Moreover, the OECD (1999) estimated annual maintenance expenses for science lab equipment ranging from $5,000 for centrifuges to over $100,000 for electron microscopes. Furthermore, expenditures on lab consumables such as reactants can surpass $20,000 per year, varying depending on lab size and reactant prices, with instances of a 5 mg bottle of reactant priced at $300 per milligram (GadelHak et al., 2023). In contrast, in VL environments, simulated equipment does not degrade, and chemical reactants remain constant, eliminating the expenses associated with conducting experiments in physical labs.

However, it is essential to acknowledge that, like any educational technology tool, a VL has its drawbacks. These include the lack of students' development of practical and physical handling skills, which are crucial for manipulating tangible objects. Additionally, in a VL, students must follow computer instructions without lab supervisors, potentially disadvantaging those lacking technological proficiency.

Recently, the number of studies conducted on VLs has surged. However, most of these studies have primarily focused on VLs' potential to enhance students' academic performance. For instance, Davenport et al. (2018) investigated the impact of VLs on chemistry learning using a sample of 1300 secondary school students. Their findings revealed that students who utilized VLs demonstrated improved performance on both pre- and post-tests. Similarly, Kapici et al. (2022) employed a factorial quasi-experimental design to explore the effects of exposing students to traditional laboratory methods and VLs on their theoretical understanding and inquiry skills. The study involved 116 intermediate school learners, and the results indicated that conventional labs and VLs were equally effective in enhancing students' comprehension of science concepts. Despite the plethora of studies highlighting VLs' efficacy in improving students' academic performance, limited research has explored teachers' perceptions of VLs. This gap in the literature is particularly striking, given the assertions made regarding VLs' effectiveness in enhancing student outcomes.

Science Teachers' Perceptions of VLs

While various factors influence science teachers' utilization of technology, their perceptions of this technology play a pivotal role in determining its adoption (Gouseti et al., 2023; Regan et al., 2019). Ertmer (2005) contended that internal factors such as perceptions significantly influence teachers' adoption of technology, outweighing factors like technology access. Similarly, Larijani and Abedi's (2021) qualitative investigation of Tehran teachers' perceptions regarding technology use in classrooms found that successful integration occurred even under restricted access conditions. This aligns with Davis's (1989) assertion that "user acceptance is pivotal in determining the success or failure of any technology" (p. 23). Moreover, Shambare et al. (2022) argue that teachers with the necessary skills to integrate technology into their lessons may refrain from doing so if they hold negative perceptions of it. Therefore, we must comprehend teachers' perceptions of technology before considering its implementation. Consequently, this paper presents a study aimed at understanding teachers' perceptions of teaching with VLs in rural schools in developing countries.

In many developing countries, particularly South Africa, incorporating VLs into education remains mainly theoretical, with limited published research available on the subject. The existing literature on virtual learning environments is sparse. However, studies conducted by Zhane'Solomon et al. (2018), Penn and Ramnarain (2019), Penn and Umesh (2019), Shambare and Simuja (2022), Matome and Jantjies (2021), and Ramnarain and Penn (2021) provide some insights. For example, Zhane'Solomon et al. (2018) explored how teachers perceive virtual reality (VR) as a tool for science education. Despite being viewed as valuable and user-friendly, the study's ten lecturers noted that the current adoption of VR for teaching and learning is hindered by issues such as inadequate infrastructure, funding constraints, and a lack of necessary VR skills.

Conversely, Penn and Ramnarain (2019) conducted a mixed-methods study on university students' perceptions of virtual chemistry simulations. Their qualitative findings revealed that students felt empowered while interacting with the virtual environment. Moreover, they believed the virtual setting enhanced their understanding of chemistry concepts. Despite recognizing the usefulness and validity of simulations, students acknowledged that they could not fully replace hands-on laboratory work. The researchers emphasized the significance of their findings for science education, particularly in institutions lacking adequate laboratory facilities. Notably, all the studies mentioned above were conducted in university settings, with none exploring the perceptions and experiences of school teachers regarding the use of VLs in rural secondary schools.

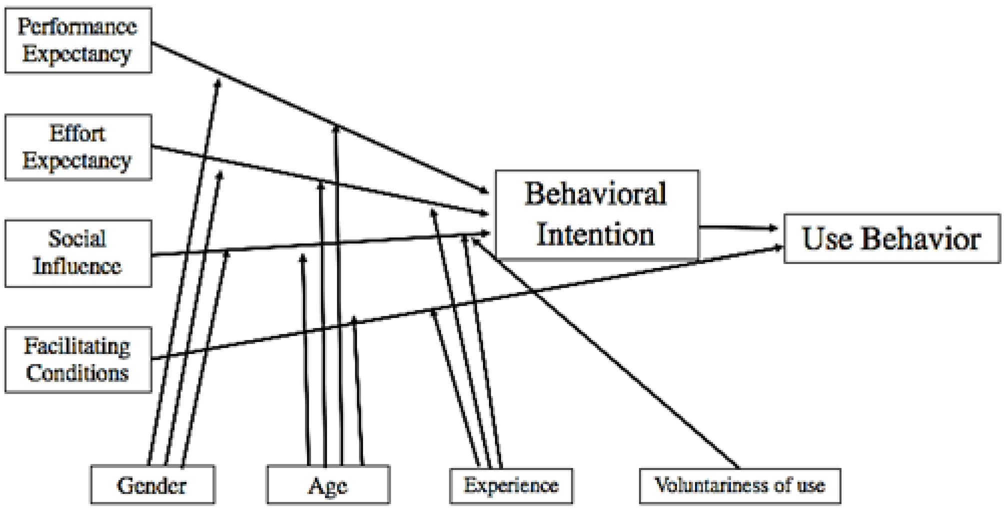
Similarly, Matome and Jantjies (2021) undertook a mixed-methods study investigating South African university students' perceptions of VR. Their research assessed how VR could enhance academic learning, and their findings indicated that VR could indeed facilitate teaching and learning in university settings. However, this literature review highlights a notable imbalance, with most studies conducted in university environments rather than secondary school contexts, especially those in rural areas. Therefore, the research presented in this paper seeks to address this knowledge gap by examining science teachers' perceptions and experiences of using VLs as a pedagogical tool.

THEORETICAL FRAMEWORK

Numerous factors affect the acceptance of novel technologies like VLs in educational settings, including attitudes, social requirements, and reluctance toward adoption. Our approach was guided by the unified theory of acceptance and use of technology (UTAUT) framework introduced by Venkatesh et al. (2003). This framework consolidates various models, such as the technology acceptance model (TAM), theory of reasoned action (TRA), theory of planned behavior (TPB), and social cognitive theory (SCT).

The UTAUT model encompasses four moderators and four decisive constructs. These moderators include gender, age, experience, and voluntariness, which influence the decisive constructs. According to Venkatesh et al. (2003), the primary constructs include performance expectancy (PE), effort expectancy (EE), social influence (SI), and facilitating conditions (FC). These decisive constructs directly shape an individual's acceptance or rejection of a technology, consequently impacting their use behavior.

Figure 1. Unified theory of acceptance and use of technology



(Source: Venkatesh et al. (2003, p. 447))

Venkatesh et al. (2003) characterized PE as the degree to which an individual believes that employing information and communication technology (ICT) will enhance their job performance. In this study, we interpret PE as the extent to which science teachers in rural secondary schools in developing countries perceive that VLs can enhance their effectiveness in teaching science. Furthermore, according to Venkatesh et al. (2003), EE denotes a person's perceived comfort level when using ICT. We conceptualize EE as pertaining to rural school science teachers' perceptions of the ease with which they can incorporate VLs into their teaching practices.

Additionally, Venkatesh et al. (2003) defined SI as an individual's perception of the opinions of those close to them regarding their use of ICT. We perceive SI as providing insights into rural science teachers' understanding of how their principals, department heads, and peers perceive their integration of technology in rural secondary school settings. Moreover, Venkatesh et al. (2003) defined FC as the degree to which an individual believes that administrative and technological infrastructures are in place to support and facilitate the use of technology. In this study, we interpret FC as rural science teachers' perception of the availability of expertise, knowledge, skills, resources, and support necessary for incorporating VLs into their teaching.

Furthermore, behavioral intention (BI), which we perceive as rural science teachers' intention to utilize VLs in their teaching, is influenced by the four determining constructs of the UTAUT model (PE, EE, SI, and FC; Venkatesh et al., 2003). Consequently, FC and BI impact actual usage behavior (UB; Venkatesh et al., 2003). In this research, we understand UB as the tangible utilization of VLs for teaching and learning by science teachers in rural schools in developing countries.

In this study, we employed the UTAUT model to gain a deeper understanding of rural science teachers' perceptions and experiences regarding VL integration into their teaching practices. Additionally, it is essential to note that our study's objective was not to ascertain, for example, whether male participants exhibit higher (or lower) VL usage than female participants or whether younger participants demonstrate greater (or lesser) acceptance of VLs than older ones. Therefore, we excluded age and gender as moderators from our analysis.

METHODS

Design

We opted for a qualitative case-study methodology (Merriam, 1998), underpinned by the interpretive paradigm, to delve into the perceptions and experiences of rural science teachers regarding the integration of VLs into their teaching practices. Specifically, we embraced a phenomenological approach (Bakanay & Çakır, 2016). Phenomenology was deemed most appropriate as it allows for exploring teachers' perceptions, attitudes, and understandings of utilizing VLs in teaching. This methodology is rooted in the belief that each teacher's perception and experience of employing technologies directly influences their acceptance and usage of those technologies.

Furthermore, as researchers, we needed to acknowledge and attempt to set aside our biases to genuinely understand the participants' interpretations. Hence, we determined that a phenomenological research methodology would be most appropriate for this study (Simuja et al., 2016; Squires, 2023). Before collecting data, we thoroughly reviewed the existing literature and engaged in reflexivity exercises to acknowledge our potential biases. Later on, during data collection, we employed in-depth semi-structured interviews and sharing circle discussions to allow participants to express their views freely, reducing interviewer/moderator bias. In addition, we utilized purposive sampling techniques during participant recruitment to ensure diversity and minimize selection bias. During data analysis, we employed multiple coders to enhance reliability and maintained an audit trail to document decisions and ensure transparency. We also engaged in ongoing reflexivity exercises and peer debriefing sessions to mitigate potential researcher bias.

Additionally, as phenomenological researchers, we identified several guiding assumptions. Firstly, we regarded the teachers as active participants consciously engaging in the deliberate use of technology. Secondly, we acknowledged the teachers' capacity to construct perceptions and experiences of educational technologies, make informed choices, and reflect on their actions. Thirdly, we remained mindful of the individual and collective contexts and circumstances that shaped the teachers' perceptions and experiences of utilizing VLs in their classrooms.

Moreover, employing qualitative methods (Merriam, 1998), such as sharing circle discussions and semi-structured interviews, allowed us to effectively access and negotiate the teachers' perceptions and experiences without imposing external biases.

Research Setting

We chose secondary school science teachers from five schools in the Joe Gqabi Education District in South Africa. This district is predominantly rural and is characterized by high levels of deprivation, low socioeconomic status, and widespread poverty (Thobi, 2022). Many students in this district hail from rural households reliant on subsistence farming and government social assistance as their primary sources of income. White and Downey (2021) found a noticeable correlation between the degree of rurality and remoteness and a decline in educational standards. For example, statistics show that in Mount Fletcher, only 16.4% of the population holds a secondary school certificate as their highest qualification, with merely 4.9% having attained a higher education degree, as per the most recent census data from 2023 (Stats, 2023).

Participant Selection

We employed purposive sampling to gather the specific knowledge we aimed for, selecting seven participants for our qualitative and interpretive study (Campbell et al., 2020). This enabled us to select individuals who could offer the most insightful perspectives on the issues under investigation (Barratt et al., 2015; Campbell et al., 2020). Purposive sampling, while valuable for selecting participants with specific characteristics relevant to one's research objectives, does

Table 1. Information about participants

Teacher (pseudonym)	Age	Gender	Qualifications	Teaching experience (years)
Teacher 1	39	Female	BEd Life Sciences	7
Teacher 2	33	Male	BEd Physical Sciences	11
Teacher 3	58	Female	BEd Life Sciences	27
Teacher 4	29	Male	BEd Life Sciences	8
Teacher 5	25	Female	BEd Agricultural Sciences	3
Teacher 6	47	Male	BEd Life Sciences	15
Teacher 7	43	Female	Bed Life Sciences & Math	12

introduce certain limitations, including the potential for sampling and researcher biases (Barrat et al., 2015). To address these concerns, we provide a thorough rationale for selecting specific teachers. We aimed to ensure representation from diverse rural schools and science educators with varying levels of experience and perspectives on VL adoption. However, we acknowledge that this approach may limit the generalizability of our findings to the broader population of science teachers in rural schools. To mitigate these limitations, we have taken measures such as providing detailed descriptions of participant selection criteria and research sites to enhance the applicability of our findings to similar settings.

Sample Size and Sample Size Determination

According to Boddy (2016), employing sample sizes as small as 1 to 12 participants is justifiable in qualitative research. Malterud et al. (2016) provide a rationale for using small samples by suggesting that fewer participants are required when the sample contains highly relevant information for the study. In line with these perspectives, we chose a sample size of seven participants, prioritizing in-depth insights over statistical representativeness due to the qualitative nature of our study. We utilized purposive sampling to select participants with diverse perspectives on VL adoption among rural science teachers. Additionally, resource constraints, including time and budget limitations, influenced our sample size decision. Table 1 presents biographical information about the seven selected teachers.

Workshop

Before commencing the study, we conducted a 5-day workshop on integrating VLs into the classroom setting. We provided seven laptops from our institution's community engagement project for some participants, while the remaining three participants utilized the researchers' laptops. The workshop served as a crucial intervention to provide professional development opportunities and support for science teachers in rural schools to enhance their understanding and integration of VLs into their teaching practices. Structured with hands-on training sessions, interactive demonstrations, collaborative lesson planning activities, and peer-to-peer discussions, the workshop covered various aspects of VL integration. Its primary objectives were to familiarize teachers with the functionalities and benefits of VLs, demonstrate effective integration strategies, and create a supportive community of practice. The workshop likely increased participants' confidence and competence in using VLs and fostered a sense of community. It may have also influenced their perceptions of the value of VLs in enhancing student engagement and conceptual understanding in science education.

Ethics Approval

We obtained ethics clearance from our affiliated university and the Provincial Department of Education before commencing data collection. Prior to collecting data, we ensured that all participants voluntarily signed a consent form after thoroughly reviewing the study's objectives. Additionally, participants were informed of their right to withdraw from the study at any point if they wished to do so. We adhered to all ethical procedures throughout the research process, including maintaining anonymity and confidentiality.

Data Gathering

We gathered data for our study through semi-structured interviews, sharing circle discussions (a form of focus group discussions rooted in Indigenous practices), and document analysis. The semi-structured interview approach allowed us to glean detailed insights from participants without redundancy (Patton, 2014). Through adept question framing, we fostered rapport with participants, clarified their perspectives, and elicited comprehensive information on the phenomenon under investigation.

Drawing from Indigenous worldviews, sharing circles promote collaborative meaning-making (Chilisa, 2017; Hanson & Danyluk, 2022; Lavallée, 2009). Common in African and Indigenous contexts, these circles often convene around communal spaces such as fireplaces, facilitating communal discourse. Teachers frequently engage in circle discussions during breaks, even in rural school settings. In our research, sharing circles allowed us to gather insights into group perspectives, experiences, and perceptions, enriching our collective knowledge.

From February to March 2021, we conducted seven interviews and two sharing circles, each lasting 30 to 45 minutes, prioritizing participant convenience. To ensure anonymity, we assigned pseudonyms to the participants. Document analysis complemented these methods, offering additional insights into technology integration guidance within South African education policy documents.

Data Analysis

In our data analysis process, we employed a thematic approach to identify, organize, analyze, and summarize themes and patterns in the data (Braun & Clark, 2006). This process was complex, iterative, and reflexive rather than linear or systematic. We began to analyze and interpret data during the semi-structured interviews and sharing circles as potential themes emerged. Subsequently, we transcribed the audio-recorded files into written text using Microsoft Word. Figure 2 illustrates the six-phase thematic analysis framework developed by Braun and Clark (2006), which we adhered to in our study.

Despite the structured progression through the six phases, analysis typically involves a recursive approach, moving back and forth between these phases. After completing the thematic data analysis framework's six phases, we conducted a thorough analysis, crafting detailed narratives for each identified theme and assessing their relevance to the research questions and overarching narrative of the data. We explored the themes, considering whether they contained sub-themes, and conducted a comprehensive analysis of each theme in relation to the research questions. We defined and succinctly described the themes, assigning appropriate titles to each. Subsequently, we convened meetings to deliberate on the data analysis process. Two prominent themes surfaced through data analysis: performance expectancy and effort expectancy. These overarching themes comprised five sub-themes: convenience and accessibility, affordability, state-of-the-art laboratory facilities and modern reagents, ensuring a safe experimental environment, and eliminating the direct manipulation of equipment.

RESULTS

In this section, we delineate the study's findings regarding teachers' perceptions and experiences of teaching with VLs in a developing country. Due to ethical considerations, we cannot disclose the name and manufacturer of the VL software used in the study. Table 2 below summarizes the themes that emerged from the data analysis.

Table 2. Rural teachers' perceptions and experiences of VLs in a developing country

Theme		Sub-theme
1	Performance expectancy	Convenience and accessibility
		Affordability
2	Effort expectancy	State-of-the-art laboratory facilities and modern reagents
		A safe environment for experimentation
		Elimination of direct handling of equipment

Performance Expectancy

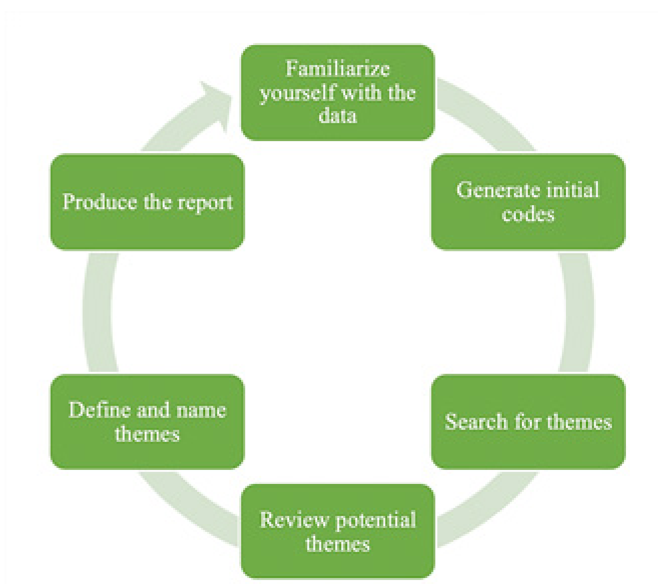
Convenience and Accessibility

Every teacher in the study acknowledged VLs as a valuable platform for conducting authentic experiments. One potential explanation for this perception is the versatility of VLs, which allows both teachers and students to engage in experiments within and beyond the confines of the classroom. The following remarks illustrate the teachers' perspectives regarding the user-friendliness of VLs:

In contrast to the constraints of a physical laboratory, where my students and I must adhere to specific schedules and be physically present in a lab, virtual labs offer us the flexibility to conduct experiments at our convenience. We no longer require access to a dedicated lab building, which is nonexistent at my school. (Teacher 1)

This statement highlights the potential of incorporating VLs into science education to mitigate the constraints linked to the necessity of being physically present in a lab setting. Additionally, VLs provide students with the flexibility to conduct experiments at their preferred pace, easing the burden on slower learners to match the pace of their peers. This indicates that VLs can accommodate various

Figure 2. Thematic analysis framework



(Source: Adapted from Braun and Clarke (2006, 2012))

learning styles by enabling students to repeat experiments until they fully understand the concepts. Regarding the accessibility of VLs, Teacher 6 remarked:

I appreciate the usefulness of VLs due to their capability for unlimited simultaneous access from multiple locations. This feature enables my students to engage in numerous experiments even outside the classroom. With the accessibility of VLs from their homes via mobile devices, experimentation can persist uninterrupted, even during summer vacation.

These observations regarding VLs' accessibility imply that they allow for indefinite and simultaneous access from different locations. Consequently, numerous students can conduct their experiments concurrently without sharing a physical laboratory space.

Affordability of VLs

In alignment with Lestari and Supahar (2020), our study's findings demonstrate that teachers view VLs as a cost-effective solution suitable for rural schools with constrained resources. Teacher 2, for example, mentioned:

I am unable to teach my students any experiments due to the absence of a laboratory at my school. Even if we had one, the cost would still be prohibitive. The expenses primarily stem from acquiring and maintaining modern laboratory equipment, as well as ensuring a continuous supply of consumables like chemicals. Consequently, VLs present a viable solution for significantly reducing laboratory costs while still facilitating the necessary experiments.

In addition, Teacher 7 stated that:

The fact that VL experiments are carried out in a simulation-based environment makes them particularly useful because, once created, the simulations can be used as many times as necessary without incurring additional operational costs. This is because chemical reagents and lab equipment do not degrade or expire in VL applications. Due to the cost of the real lab, this feature of VLs enables students from schools with limited resources, such as mine, to conduct basic experiments that they otherwise would not be able to do.

Nevertheless, while our study revealed that teachers deem VLs to be affordable, it is important to note that parents should not be required to incur any expenses.

Effort Expectancy

State-of-the-Art Laboratory Facilities and Modern Reagents

The teachers pointed out that the contemporary and high-caliber laboratory equipment within VLs also facilitates their efficacy. For instance, Teacher 4 remarked:

In my previous two schools, we had physical laboratories, but the equipment was antiquated and obsolete, often yielding inaccurate and inconsistent experimental outcomes. It was during this experience that I recognized the necessity for modern equipment and contemporary chemical reagents in scientific experiments. In this respect, VLs would be ideal, as they are more prone to furnish dependable results with minimal margin for error owing to their state-of-the-art apparatuses.

Teacher 5 added that:

Virtual experiments, leveraging modern technology, inherently minimize experimental error. Nevertheless, the majority of rural schools find themselves unable to afford modern instruments due to their exorbitant costs. Consequently, VLs could serve as a viable substitute for physical laboratories.

These quotes illustrate the teachers' acknowledgment of VLs' accessibility to high-quality laboratory tools for conducting science experiments. Rani and Dwandaru (2019) similarly documented that VLs can potentially supplant expensive lab equipment with modern virtual counterparts.

A Safe Environment for Experimentation

Based on the participants' feedback, safety emerged as a paramount consideration in utilizing VLs. Most teachers concurred that VLs mitigate the physical hazards associated with traditional laboratory settings. For example, Teacher 3 noted:

Drawing from my years of experience as a science teacher, I am well aware of the potential hazards inherent in conducting experiments within a physical laboratory environment. However, based on my recent encounters with VLs, I am confident that such risks are virtually nonexistent when utilizing this platform.

When prompted by the researchers to provide further details regarding the specific hazards encountered in traditional laboratory settings, Teacher 3 elaborated:

The common hazards often encountered in traditional laboratories encompass risks associated with fire, flammable or corrosive chemical substances, as well as handling animal specimens. These include, but are not limited to, burns, electric shocks, gas leaks, adverse chemical reactions, and the potential for infections.

Teacher 2 further noted that:

I believe that the utilization of VLs offers students the opportunity to engage in experiments that would otherwise pose significant risks in a conventional laboratory. Additionally, VLs allow students to simulate and comprehend the behaviors of both living and non-living entities under extreme temperature conditions. Such simulations would be either too hazardous or impractical to replicate in a physical lab setting.

During the subsequent discussion, Teacher 3 raised an important point regarding the safety benefits that VLs could offer, especially for students with physical disabilities:

Physically challenged students can utilize VLs as a secure environment for conducting experiments, devoid of the complexities and safety hazards associated with traditional laboratory equipment.

Teacher 3's perspective underscores the advantage of conducting experiments within a VL. This eliminates the need for students, particularly those with physical disabilities, to move between locations to gather equipment, reducing the associated risks. Furthermore, VLs can be customized to cater to students with diverse audio-visual requirements, providing a safe and accommodating environment for experimentation, even for those facing learning challenges.

Elimination of Direct Handling of Equipment

Despite recognizing VLs' utility, teachers also voiced concerns regarding their lack of "hands-on" experimentation. For instance, Teacher 4 articulated the following apprehension:

Replacing the physical laboratory with a VL may present challenges. For instance, the tactile interaction with lab equipment and direct observation of tangible processes involve measuring real variables like temperature, mass, and pressure. These experiences foster skills essential for real-world applications.

This teacher's statement suggests that conducting experiments in a VL may deprive students of authentic experiential learning crucial for real-world applications, potentially hindering their development of problem-solving skills. Working in real laboratories often involves encountering systematic and random errors, which students learn to recognize and address through cognitive adjustments. In contrast, students using VLs may not experience these errors, leading to the inaccurate construction of reality models and potential challenges in responding to real-life processes. Additionally, VL users may be unable to consider alternatives when faced with experimental failures, impacting their critical thinking skills.

DISCUSSION

The current study examined the perspectives and encounters of science teachers regarding incorporating VLs into rural secondary educational institutions, particularly in South Africa. The results revealed that the teachers perceived VLs as beneficial owing to their convenience, accessibility, affordability, and provision of contemporary laboratory amenities in a secure setting conducive to conducting experiments.

The revelation that teachers found VLs convenient and accessible resonates with research by Lestari and Supahar (2020), who underscored VLs' capability for simultaneous access from multiple locations, facilitating the execution of numerous experiments. This aspect addresses spatial constraints encountered by rural schools in the Eastern Cape province, allowing students to continue their experiments remotely or during breaks, as highlighted by certain teachers in our study. By offering remote access to laboratory resources, VLs can mitigate the limitations imposed by geographical isolation and resource constraints, thereby enhancing educational equity and access for students in rural areas. However, while VLs offer convenience and accessibility, they may also exacerbate existing disparities in student access to technology and digital resources. Rural schools, in particular, may face challenges related to internet connectivity, technological infrastructure, and digital literacy, which could impede equitable access to VLs for all students.

Furthermore, teachers regarded VLs as a cost-effective substitute for physical laboratories. Unlike conventional labs requiring costly equipment and consumables, a VL does not entail additional operational expenses. This finding echoes the sentiments of Bogusevschi et al. (2020), Mtsi and Maphosa (2016), and Ramnarain and Hlatswayo (2018), who emphasized the financial hurdles associated with state-of-the-art laboratory facilities in economically disadvantaged rural areas. This recognition of VLs as a cost-effective alternative to traditional laboratory setups by the teachers holds crucial implications for alleviating financial burdens on rural schools, which often struggle to maintain well-equipped science facilities. Redirecting resources from costly equipment and consumables to VL implementation can enable schools to allocate funds toward other educational priorities, such as teacher professional development and curriculum enrichment. However, while the teachers in this study perceived VLs as cost-effective, Kapilan et al. (2021) caution that the cost of implementing and maintaining VLs, including subscription fees, software updates, and technical support, may pose financial burdens for resource-constrained schools, offsetting the perceived affordability benefits.

Moreover, teachers appreciated the availability of modern, high-quality laboratory equipment in VLs, aligning with Davenport et al.'s (2018) argument that the contemporary equipment in VLs enables more precise and efficient experimentation. However, a notable divergence between this study and prior research lies in the educational context, with most existing studies centering on university environments. Therefore, this study provides insights into VL adoption across varied educational landscapes.

Another significant finding involved study participants' acknowledgment of the absence of physical manipulation of equipment in VLs, a potential drawback of this technology. This observation aligns with previous critiques of VLs (Ramnarain & Penn, 2021; Shambare & Simuja, 2022), which have some limitations. One significant concern is the potential impact of the lack of physical manipulation in VLs on students' learning experiences and skills development. Hands-on practical activities are crucial in science education, enabling students to develop critical thinking skills, problem-solving abilities, and a deeper understanding of scientific concepts (Fernandez et al., 2023; Hodson, 2014). The sole reliance on virtual simulations may limit students' opportunities for tactile exploration and experimentation, hindering their overall learning outcomes.

Notably, the lack of physical manipulation in VLs leads to the need to consider alternative perspectives on VL integration, including hybrid approaches that combine virtual and physical laboratory experiences. Integrating VLs as supplements to traditional laboratory activities rather than replacements could provide a balanced approach that harnesses the benefits of both modalities while addressing their respective limitations.

CONCLUSION

The research suggests that VLs have the potential to significantly enhance science education in rural areas of developing nations. Teachers view VLs as accessible, affordable, and convenient for conducting experiments, even in the absence of physical resources. However, the inability to engage with physical equipment may pose a limitation. This underscores the potential benefit of adopting a hybrid approach, integrating VLs with hands-on experiences where feasible. Ultimately, the study advocates for the adoption and further exploration of VLs in rural schools to improve the quality of science education and address resource constraints. The findings have implications for educational policies aimed at enhancing science teaching in resource-constrained rural schools in developing countries. Moreover, future research should focus on experimentally validating teachers' perceptions and experiences with VLs for teaching in rural schools and quantitatively assessing their impact on students' academic performance. This would provide empirical evidence to support the efficacy of VLs in enhancing science education outcomes in these settings.

LIMITATIONS

One notable limitation of this study is its relatively small sample size, comprising seven science teachers from rural secondary schools in South Africa. While efforts were made to select participants with diverse backgrounds and experiences, the limited sample size may restrict the generalizability of the findings to other contexts or populations. Additionally, the study relied primarily on self-reported data obtained through interviews and sharing circle discussions, which could be subject to social desirability bias or recall errors. Furthermore, the study focused solely on science teachers' perspectives, overlooking the viewpoints of other stakeholders, such as students, school administrators, or educational policymakers. Future research could address these limitations by including larger and more diverse samples, employing mixed-methods approaches to triangulate data, and exploring multiple perspectives to provide a comprehensive understanding of VL adoption in rural secondary schools.

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Correspondence concerning this article should be addressed to Brian Shambare, email: G19S3620@campus.ru.ac.za.

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Brian Shambare is an ICT in Education Doctoral scholar at Rhodes University. His current research explores technology integration in rural science teaching and learning contexts. Particularly, his work focusses on the use of Virtual Laboratory for rural science teaching.

Clement Simuja is a Senior Lecturer ICT in Education and Philosophy Dr Simuja's research uses critical social theories and philosophical thinking to examine the ways in which historically underserved schools in developing countries appropriate information and communication technologies (ICT) to improve educational practices.