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Understanding the Enabling and Constraining Factors in Using the Virtual Lab:
Teaching Science in Rural Schools in South Africa

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ABSTRACT

It is commonly accepted that learners gain better understanding of science concepts when they perform 'hands-on' experiments in the lab. However, the lack of lab infrastructure, particularly in most rural schools, negatively affects the teaching of science. With the increasing potential of ICT to education, virtual laboratories (VL) have emerged as an alternative to the real laboratories. Like any ICT educational tool, it is important to understand the enabling and constraining factors in teaching with the VL. Therefore, this study presents the enabling and constraining factors in using the VL from teachers' perspectives. Particularly, this study is guided by the research question: What are the enabling and constraining factors in using the virtual lab to mediate learning of science through scientific experiments? Data were collected through semi-structured interviews and lesson observations. The results reveal that the Virtual Lab has several enabling factors and also revealed some constraining factors. Nevertheless, findings suggest the VL is a suitable alternative to the real lab.

KEYWORDS

Constraining Factors, Enabling Factors, Information and Communication Technology (ICT), Science Education, Scientific Experiments, Virtual Lab

INTRODUCTION

Effective teaching and learning of science rely on the learner's experimentation in science laboratories, where theoretical principles are verified, and the teaching is given a practical orientation (Liu et al., 2021; Vaez & Potvin, 2021; El, Berrada & Burgos, 2021). In South Africa, like in many other countries, the Curriculum and Assessment Policy Statement (CAPS) directs that "learners must be

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able to plan and carry out scientific experiments that require some practical ability in science subjects" (CAPS, 2011, p.15). This is because science experiments play a crucial role in assisting the learners in gaining experience through concrete materials, improving learners' problem-solving skills, enhancing learners' abilities to understand practical problems, and improving learners' attitudes towards science (Teig, 2021; Gyllenpalm, Rundgren, Lederman & Lederman, 2021).

While real experimentation with conventional lab apparatus and equipment is greatly desired, most rural schools in South Africa face limited financial resources to acquire and maintain lab equipment and infrastructure, particularly in the Eastern Cape province. Mtsi and Maphosa (2016); Tsakeni, Vandeyar and Potgieter, (2019); Beck and Blumer (2021); Edwards, McKay, and Shea (2021) reported that science learning had been restrained by the deficiency or inadequacy of laboratory equipment in most schools. From this viewpoint, it is imperative to explore new unconventional alternative laboratory environments where teachers and learners can conduct the required experiments while achieving the pedagogical objectives of science curricula. With the current advancement in the use of technology as the 'new normal', a symbiotic relationship has emerged between the fields of science education and ICT in education. This has resulted in the proliferation of new technologies in teaching and learning. One of the novel technological advancements in the teaching and learning of science is the use of Virtual Lab (VL). VL is a simulated version of a traditional laboratory in which the learner is provided with instruments that are virtual representations of real objects used in conventional laboratories (Lestari & Supahar, 2020). With VL, the building and physical lab tools are transformed into software applications. There are many free VL software available for schools to use, and some are mobile app versions that do not need school internet infrastructure.

Recently, a robust symbiotic relationship between science education and ICT in education has developed in which the two are joined by an 'umbilical cord' of mutual benefit. This relationship has drastically transformed the laboratory science education landscape (Kumala et al., 2021; Eliyawati et al., 2021), and a new form of laboratory, Virtual Lab (VL), has emerged. VL is a simulated version of a traditional laboratory in which the learner is provided with instruments that are virtual representations of real objects used in conventional laboratories (Lestari & Supahar, 2020). With VL, the building and physical lab tools are transformed into software applications. Currently, there are many free VL software available for schools to use, and some are mobile app versions that do not need school internet infrastructure.

In South Africa, the VL is still at a conception stage, and subsequently, little research on the VL has emerged in the literature compared to European and Western countries. The few studies available on virtual learning environments in South Africa are those conducted by Zhane'Solomon, Raghavjee, Ndayizigamiye and Natal (2018); Penn and Ramnarain (2019); Penn and Umesh (2019); Matome and Jantjies (2021); Ramnarain and Penn (2021). Specifically, Zhane'Solomon et al. (2018) focussed on university lecturers' perceptions of Virtual Reality (VR) as a science teaching and learning platform. In contrast, Penn and Ramnarain (2019) focussed on South African university students' attitudes and perceptions towards chemistry learning in a virtually simulated learning environment. In addition, Matome and Jantjies (2021) focused on student perceptions of Virtual Reality in Higher Education. All these studies have been conducted in university contexts, and none of the studies has focused on understanding the enabling and constraining factors of teaching with the VL in rural and resource-constrained school contexts. According to the researchers' literature review, this study was the first attempt to explore rural science teachers' experiences in teaching with the VL in resource-poor schools. Considering this, the present study sought to bring to fore new knowledge about the experiences of rural secondary school science teachers in teaching with the VL.

With the potential of the VL to enhance the teaching and learning of science, we conducted this interventionist study in which we sought to investigate the enabling and constraining factors in teaching with the VL from the perspective of the teachers. The study is premised on the precept that an understanding of the enabling and restraining factors of the VL would help ensure effective use of the technology. Mainly, the study is guided by the research question: What are the enabling and

constraining factors in using the VL to mediate science learning through scientific experiments? To foreground the response to the research question, the paper starts by reviewing literature related to the topic and then presents the conceptual framework that guides the study. This was followed by research methodology, data collection, findings of the research and the discussion of the results. Lastly, the paper concludes by presenting the conclusion and recommendations.

LEVERAGING THE USE OF CONVENTIONAL AND VIRTUAL LABORATORIES IN SCIENCE EDUCATION

Laboratory activities have an essential role in science learning (Sutarno, Setiawan & Suhandi, 2019). Laboratory activity in science teaching and learning is often referred to as a scientific experiment. Conducting scientific experiments in science learning is a cornerstone in developing learners' science problem-solving skills, which include formulating questions and hypothesis, carrying out experiments, measuring, reviewing what is already known in light of experimental evidence, using tools to gather, analyse and interpret data, proposing answers, explanations and predictions, making conclusions, and communicating the results (Sutarno et al., 2019). These science processes are important because, according to Ateş and Eryılmaz (2011), learners learn better when they measure, touch, feel, make charts, manipulate, draw, record data, interpret data and make their conclusions. Moreover, laboratory activities serve as a vehicle for constructing, reconstructing, verifying, and strengthening scientific knowledge (oghlu Sharifov, 2020). Proper scientific experiments can stimulate the development of low-order thinking skills into higher-order thinking skills that allow students to function at the analysis, synthesis and evaluation levels of Bloom's taxonomy (Pedaste, Mitt & Jürivete, 2020). Scientific activities that can be used in students' learning process can use experimental laboratories or VLs (oghlu Sharifov, 2020).

A virtual Lab is a simulated version of the traditional laboratory that refer to a learner-centred approach in which the learner is provided with instruments that are virtual representations of real objects used in conventional laboratories (Lestari & Supahar, 2020). Bogusevschi, Muntean and Muntean (2020) defined VL as a highly interactive computer-based multimedia environment that brings learners into a virtual world that allows them to create and conduct simulated experiments and visualise in a 3D environment the effects of the experiment.

A VL contains a set of all apparatus such as microscopes, centrifuges, whole organisms, or individual cells, each with specific pre-programmed behaviours (Aliyu & Talib, 2019). The a learner can interact with the virtual objects to attain a set of given goals, i.e., the study of cell features, separation of cellular components, measurement of enzyme activities, quantification of cell division, etc. (Pedaste, Mitt & Jürivete, 2020). The use of creative renderings of objects and their behaviours allows the learner to experiment in the virtual freely world. According to Aliyu and Talib (2019), learners can use the graphics editor available in the framework to prepare lab reports after the exercises. Subramanian and Marsic (2001) pointed out that any stage of the lab can be captured and copied in the report document at the level of structured graphics, rather than screen bitmaps, and that the documents are stored in XML and can be reviewed and edited manually if necessary.

CONCEPTUAL FRAMEWORK

The work in this paper is grounded in the theoretical framework of TPACK. The TPACK framework, a build-up on the earlier work of Shulman (Shulman, 1986), has recently emerged as one of the most useful theoretical frameworks for thinking about the knowledge, skills, and dispositions a teacher needs to integrate technologies into the classroom effectively (Koehler & Mishra, 2009). Swenson, Rozema, Young, McGrail, and Whitin (2005, p. 222) indicated that TPACK "involves asking how technology can support and expand effective teaching and learning within a discipline while simultaneously adjusting to the changes in content and pedagogy that technology by its very nature

brings about". TPACK theorises that effective technology integration into classroom practice should consider all three elements of content, pedagogy, and technology – not in isolation but in complex, vibrant operational relationships that define teaching practice. The interaction of these elements of knowledge, both theoretically and in practice, produces the types of flexible knowledge needed to integrate technology into teaching successfully. It can be argued that knowledge of the different components of the TPACK framework does not necessarily mean the implementation of ICTs in teaching and learning. The implementation of technology in the classroom is multi-faceted. There are other factors, such as the availability of ICT infrastructure at schools and the learners' digital skills, which affect the implementation of technology in the classroom. If all factors which affect ICT adoption and use are not addressed, then implementing technology in teaching and learning might be impossible. The resulting knowledge components of TPACK are shown in Figure 1 and elaborated in Table 1.

Figure 1. The TPACK framework with context. From http://www.tpack.org

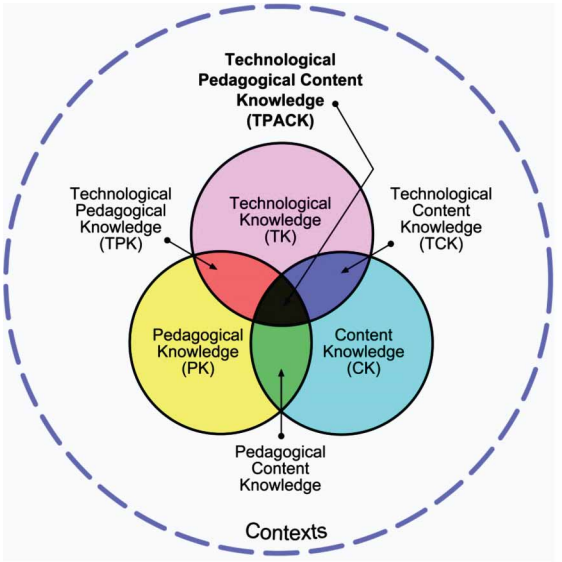

Table 1. The seven constructs in the TPACK framework (Chai, Koh & Tsai, 2010, p.564)

The Constructs	Abbreviation	Definitions
Content Knowledge	CK.	Knowledge of subject matter
Technological Knowledge	TK.	Knowledge of various technologies
Pedagogical Knowledge	PK.	Knowledge of the processes or methods of teaching
Technological Content Knowledge	TCK	Knowledge of subject matter representation with technology
Technological Pedagogical Knowledge	TPK	Knowledge of using technology to implement different teaching methods
Pedagogical Content Knowledge	PCK	Knowledge of teaching methods for different types of subject matter
Technological Pedagogical Content Knowledge	TPACK	Knowledge of using technology to implement teaching methods for different types of subject matter

This study foregrounds the TPACK framework as the analytical lens to understand teachers' experiences in using the VL due to its alignment with the purpose of the study and the possibility of the framework in helping to generate data to answer the research question of this study: What are science teachers' pedagogical and technological experiences in using the VL to mediate science learning through scientific experiments? The TPACK framework helped us as researchers in this study to understand the connections and interactions between pedagogical knowledge (how to teach) and technological knowledge (how to do so with the use of technology, i.e., the VL in our case), which are the areas that we sought to understand. In addition, the TPACK framework provides that knowledge and experiences about teaching with the technology are not context-free; therefore, all contextual factors that could impact the teachers' experiences in teaching with the VL, such as school technology policies, availability of technology infrastructure, as well as support from the School Management Teams, were considered.

RESEARCH METHODOLOGY

This study uses a qualitative case-study research design guided by the interpretive paradigm to understand the teachers' experiences in teaching with the VL. As this study explores teachers' experiences on the phenomenon of using VL in teaching and learning, phenomenology offered the most relevant form of methodology (inquiry). This qualitative study is grounded on the precept that all VL experiences and other technologies are based on an individual science teacher using technologies in teaching practices. Therefore, the best way of accessing the teacher's lived experiences was for us as researchers to identify and try to forgo our perceptions and listen to the selected participants' meanings and experiences. Subsequently, the research approach of phenomenology that prioritises examining conscious awareness through an investigation of the personal-technology relationship (Simuja & Krauss, 2016; Glasco, 2020) was deemed most appropriate.

For the study to capture the required experiences, we as researchers (phenomenologists) must recognise several assumptions that could inform the research. These include the assumptions that teachers were to be viewed as active and intentional participants in the study who are aware of their intentional use of technologies and who are capable of constructing experiences towards technologies used in their professional contexts, the choices that they make and their ability to think and reflect on their practices. To understand the participants involved in the study, we were conscious of their contexts, situations, and experiences of being in the world as individuals or collectively with other teachers and learners (Webb & Welsh, 2019).

In general, as researchers, we were also guided by the belief that participants (teachers) involved in the study are active agents in their teaching and lives, simultaneously reacting to and accepting technologies while seeking experiences. Subsequently, teachers, as any other persons, co-constitute meaning as they interact with an experience, possibilities and the limitations of technologies. Therefore, the discussion, interpretation, and investigation of the phenomenon in the study is framed in the experiences of individual teachers. Only once this knowledge was examined the study shift from the individual to the collective understanding of the nature of the unique experiences from the perspective of its lived qualities (Sonia, 2017; Sacramento, 2019).

To achieve the methodological processes in this study, a suite of qualitative methods such as semi-structured interviews, lesson observations and writing journal reflections needed to be negotiated. While the perspectives and the main intentions of the three methods were readily accessed and acknowledged for the type of knowledge being sought, the breadth of applications was less straightforward. For this interpretive and qualitative study, purposive sampling (Gemiya, 2020) was used as a technique to sample the participants. The intention of purposively selecting participants in the study was to gain a deep and clear insight into the issues under investigation (Etikan, Musa & Alkassim, 2016; Bakkalbasioglu, 2020). The participants are secondary school science teachers from four rural schools in Amathole East District in South Africa, and Table 2 contains relevant

Table 2. Information about participants

Teacher (Pseudonym)	Age	Gender	Qualification	Number of years teaching science in rural secondary school
T1	33	Male	BEd Agricultural Sciences & Life Sciences	9
T2	29	Male	BEd Physical Sciences	5
T3	37	Female	BEd Agricultural Sciences & Life Sciences	13
T4	43	Male	BEd Honours degree in Educational Leadership and Management	19
T5	39	Female	BEd Agricultural Sciences & Life Sciences	14
T6	48	Male	BEd Life Sciences	24
T7	35	Female	BEd Agricultural Sciences & Life Sciences	11

information (biographical data) pertaining to the participants. The participants attended a three-day training workshop on using VL to teach science. The researchers organised the training as part of their community engagement initiated by their affiliated university. In response, the researchers thought to take the opportunity of turning the initiative into research that could inform other teachers who are teaching in rural schools and in similar schooling contexts.

The ethics clearance was sought from the Provincial Department of Education office and our affiliated university. The participants participated in the study voluntarily, and there was no coercion or deception. Participants were also allowed to withdraw at any point. In this research, ethical protocols such as informed consent, confidentiality, anonymity, credibility and trustworthiness were guaranteed during the conduct of this research.

DATA COLLECTION AND ANALYSIS

Prior to responding to participating in this study, all participants voluntarily signed the consent form and read the purpose of the study. The participants were also informed of their right to choose not to respond to any of the formulated questions. The data collection instruments were designed to capture data that could respond to the following question: What are science teachers' pedagogical and technological experiences in using the VL to mediate learning of science through scientific experiments? The researchers aimed to explore the pedagogical and technological experiences of science teachers in using the VL to mediate learning of science through scientific experiments.

The aim was to collect data from fifteen teacher participants. However, saturation was reached when data from seven participants was collected. We concluded that saturation was reached when data from participants eight, nine and ten did not provide any new information compared to the previous participants. Thus, we collected data from seven participants. All teachers selected to participate in the study responded to the interviews, writing reflective journals and classroom observation. The semi-structured interview questions were e-mailed to the participants prior to the interview. In addition, the researchers developed a set of interview questions that are open-ended, semi-structured, and that would capture all the themes that were important for answering the research question. The interviews were conducted face to face with all Covid-19 pandemic protocols observed and audio recorded for transcription purposes. In order to mitigate the power imbalances and to build rapport and trust (Grinyer & Thomas, 2012; Brinkmann & Kvale, 2015), during interviews, teachers (participants) were given authority and confidence by making them aware that the researchers were going to learn

from their experiences before carrying out the interviews. In addition, the researchers arranged that the interviews take place at a date and time convenient for both participants and the researchers. We also gathered data through non-participant observation. This means that we were present in the classrooms but not interacting or participating (Stake, 2010). In order to minimise the constraints that can be associated with observations, we utilised carefully designed observation guides to capture all the pertinent issues for this study. Further, the observation sessions were scheduled in advance to ensure the availability of the participants. The observation method was useful as it allowed us to gauge participants' feelings about using the VL from their speech, gestures, and facial expressions.

The data analysis procedure included the researchers' use of a thematic analysis approach, which identifies, organises, analyses, and reports patterns/themes within data (Zammit, 2020). Although the researchers involved distinct processes such as transcription, organisation, coding, analysis and interpretation, the process was not linear or systematic but complex, iterative, and reflexive. For example, the interpretation and analysis were started during interviews as suggestions of themes and possible codes began to emerge. The recorded interviews were transcribed using Microsoft Word software. The transcribed texts were then analysed using NVivo, a version 22 data analysis tool. NVivo is a versatile, robust and credible tool for collecting, organising and analysing varied qualitative data types (Phillips & Lu, 2018; Elliott-Mainwaring, 2021). Each transcribed text was loaded onto NVivo and then analysed by grouping each participant's responses into categories or themes. The participants' responses were coded to the corresponding themes. The coding process involved each relevant text to a relevant theme. Using an inductive data analysis approach (MacMillan & Schumacher, 2006), the emerging pattern of themes became the source of the study findings.

FINDINGS OF THE STUDY

The findings of this study are presented in accordance with the teachers' experiences on the enabling and constraining factors on the use of VL for teaching and learning science. The findings comprise particularly the experiences of rural science secondary school teachers. These experiences were examined, specifically considering the viability or not, of the VL as an alternative to the real lab. The tendency of teacher pseudonymity was consistently observed throughout the study in compliance with the ethical requirements and to ensure the anonymity and confidentiality of the participants. Data for this study was mainly drawn from semi-structured interviews and class observations. Analysis of the data gave rise to four themes which are summarised in table 3.

Convenience and Accessibility

Like in Arista and Kuswanto (2018), all teachers in this study agreed that the VL is a convenient platform for performing science practical experiments. This is because the VL allows teachers and learners to do their experiments in and out of the school. Comments illustrating the benefits of convenience as perceived by the research participants were:

Table 3. Enabling and constraining factors of using VL to mediate learning of scientific experiments

Theme	Description
1	Convenience and accessibility
2	Safe environment for conducting experiments
3	Affordability
4	Top-class lab equipment and up-to-date reagents
5	Lack of direct 'hands-on' experimentation

Unlike the real laboratory where my learners and I have to be physically present in a lab at specified times, with the VL, we can carry out our experiments at our convenient time and place and do not need to be in a lab building that we don't even have at my school. (T1)

From this statement, it can be noted that the VL can allow learners to work at their own pace, and the slow learners may not be intimidated by the fast learners. Also, the VL can allow my learners to repeat an experiment as many times as may be required for them to understand the experiment, and this enables the VL to cater for learners with varying learning paces.

On the accessibility of the VL, T6 commented:

What I find useful about the VL is its ability to be accessed simultaneously from different locations in an unlimited way. This means that my learners can perform their experiments simultaneously even from their homes.

T6 added that:

Since the VL can be accessed by learners from their homes through mobile devices, this will ensure that learning of science practical experiments will not stop even when schools temporarily close due to the current COVID-19 pandemic.

These comments on the accessibility of the VL suggest that the VL can be accessed simultaneously from different locations in an unlimited way. This means that many learners can perform their experiments simultaneously without having to be in the same physical space.

A Safe Platform for Conducting Experiments

One of the most emphasised enabling factors of teaching with VL from the participants' responses is safety. The teachers acknowledged that the VL eliminates the physical dangers that are associated with a real lab. T5, for example, explained:

From my training as a Science teacher, I am aware that conducting experiments in a real science laboratory can expose learners to danger, and those dangers cannot occur when using a VL.

When probed by the researcher to explain further the nature of the danger, T5 continued:

The most common dangers that can occur in real labs happen especially when fire, flammable or corrosive chemical reagents or animal specimens are involved. Some of the dangers that might occur, include burns, electrical shocks, gas leakages, adverse chemical reactions, and infections. In a VL, all these lab accessories are virtual representations of the real ones and they do not cause any dangers that can happen in a physical lab.

T2 pointed out that:

I have learnt that VL enables learners to conduct experiments that could otherwise be too dangerous to perform in a real lab. For example, the VL allows learners to simulate and understand behaviours of biotic or abiotic things at extremely high or low temperatures – environments which are too dangerous or impossible to create in a real lab.

Later in the analysis, T3 raised a factor that he/she considered to be an important aspect of safety that the VL can offer in the context of the COVID-19 pandemic. The teacher did not refer to the

physical dangers that are associated with the traditional lab and eliminated by the VL. The teacher had the following to say:

With the current rising in COVID-19 infections in schools, I think when it comes to conducting science practicals the Department of Basic Education needs to promote use of VL.

This is because the teachers believe that in a VL, there is no sharing of lab instruments as in the real lab where there is a risk of handling contaminated instruments or surfaces. In addition, unlike the real lab where learners must be in the lab building, with VL, learners can perform experiments even at home. This allows for physical distancing, too and enables those learners that might be in isolation or quarantine to perform their experiments.

Affordability of Teaching Using the VL

The findings from the teachers revealed that conducting practical experiments in the VL platform is much more affordable and that resource-constrained rural schools can make use of the VL as an alternative to the real lab. This is supported by Lestari and Supahar (2020), and Kumala et al, (2021). The following are the comments from the teachers in this study. T6, for example, stated:

The reason why I do not teach practical experiments to my learners is because my school does not have a science lab. Even if my school had a science lab, I would still be unable to teach practical experiments because conducting lab experiments in real labs can be very costly especially for under-resourced rural schools such as mine. The cost arises from procurement of up-to-date lab equipment, maintenance of the equipment and constant replenishment of lab consumables. VL experiments may be a great alternative to the physical lab in terms of lowering lab costs, while still providing good laboratory experiences.

In addition, T1 explained:

What I find helpful about the VL experiments are that they are conducted within a virtual environment that uses simulations; this means that once developed, the simulations can function at no extra operational cost as many times as required. This is because in VL applications, lab equipment do not wear out, and chemical reagents do not expire. This feature of the VL allows learners from resource-constrained schools to perform standard experiments that they would otherwise be unable to perform due to the cost associated with the real lab.

These comments, however, contradict the findings of Tatli and Ayas (2013) and Shidiq, Permanasari and Hendayana (2021), who indicated that the VL is not as affordable. They argued that the development of VL and constant maintenance (i.e., debugging), the price of devices, instruments, servers, and expertise needed to develop the software and its updates could potentially be a major cost factor, and this cost should be considered when deciding whether VL is affordable. One of the teachers, T3, expressed concern that:

The majority of my learners come from poor communities where their parents are farm workers who may not be able to buy the gadgets or smartphones that are needed to operate the VL. Whilst I appreciate that VL lowers running costs for the school, the cost is exorbitant on most parents to buy the gadgets.

To this concern, the researchers informed the teacher that the Eastern Cape Department of Education is in the process of rolling out tablets to all learners and that these tablets will have sim

cards that will be loaded to a monthly allowance of 4 GB of data. Hence, the parents will not be incurring any costs.

Top-Class Lab Equipment and Up-to-Date Reagents

Another enabling factor in VL uses that the participants reported is the availability of top-class lab equipment and up-to-date reagents in the VL. T4 pointed out that:

In my previous two schools, we had real labs, but those labs, just like most rural schools, were equipped with outdated equipment and expired chemicals which often gave inconsistent and inaccurate results. That's when I realised that in science experiments, modern instruments and up-to-date chemical reagents should be used and, in this regard, the VL is most ideal as it is more likely to give reliable results with minimum chances of error and reporting incorrect results because of the modern apparatus that it uses.

In addition, T6 stated that:

Virtual experimentations have the benefit of reducing error because they use top-notch modern equipment. The modern instruments are very expensive and most rural schools cannot afford them. the VL replaces the expensive real equipment with up-to-date simulated versions of the equipment.

These statements indicate that the teachers find the VL to be beneficiary in their teaching of science experiments in terms of the availability of top-class laboratory equipment. Similar findings were reported by Rani, Mundilarto, Warsono and Dwandaru (2019), who found that the VL can replace the real expensive equipment with up-to-date simulated versions of the real equipment.

DISCUSSION OF FINDINGS

Some of the enabling and constraining factors of using VL to mediate learning of scientific experiments as investigated by Castelló et al., (2020) were confirmed in this study. For example, this study found that the VL offers improved convenience and accessibility for conducting practical experiments. This is because, contrary to the physical laboratory where teachers and learners must be physically present in the lab at specific times, with the VL, teachers and learners can conduct their experiments at their convenient time and place and do not need to be in a lab building. This is also consistent with the findings by Arista and Kuswanto (2018) and, Aliyu and Talib (2019), who indicated that VL could be used both in and outside school and could improve convenience when conducting experiments. This is particularly more important in maintaining social distancing by avoiding being in the same physical building in the context of the COVID-19 pandemic.

Another enabling factor that this study found in using VL to mediate learning of scientific experiments is safety. All the teacher participants agreed that VL provides a safe environment for conducting experiments. Like Aliyu and Talib (2019), the teacher participants in this study acknowledged that conducting experiments in real science laboratories can expose learners to danger, especially when fire, chemical reagents or animal specimens are involved and that some of the dangers that might occur include burns, electrical shocks, gas leakages, adverse chemical reactions, and infections. The teachers further acknowledged that the use of the VL eliminates the physical dangers that are associated with the use of the physical lab. This confirms the findings of Puntambekar (2021), who found that VL enables learners to conduct experiments that could otherwise be too dangerous to perform in a real lab. They also reported that VL allows learners to visualise places that could be dangerous or impossible to visit, such as the deep ocean floor and high mountains. This study suggests that the VL is not only safe

against physical dangers but could also be a safe environment against contagious pandemics such as the current COVID-19.

As far as the affordability of using the VL for teaching is concerned, the findings of this study contradict Tatli and Ayas (2013), who pointed out that using VL for teaching is very costly. They argued that development of VL and constant maintenance (i.e., debugging), the price of devices, instruments, servers, and expertise needed to develop the software and its updates could potentially be a major cost factor and this cost should be considered when deciding whether VL is affordable. On the other hand, this study confirms the findings of Lee and Sulaiman (2018) and Lestari and Supahar (2020), who indicated that VL experiments may be a great alternative to the physical lab in terms of lowering lab costs while still creating good laboratory experiences. This is because in VL experiments are conducted within a virtual environment that uses simulations, this means that once developed, the simulations can function at no extra operational cost as many times as required. In addition, in VL, equipment does not wear out, and chemical reagents do not expire. This feature of the VL allows learners from resource-constrained schools to be able to perform standard experiments which they would otherwise be unable to perform due to the cost associated with the real lab.

Lastly, this study revealed that the availability of top-class lab equipment and up-to-date reagents is a feature that the teacher participants considered to be very important. Like Destino et al., (2021), the participants in this study appreciated the fact that in science experiments, modern instruments and up-to-date chemical reagents are necessary as they are more likely to give reliable results with minimum chances of error and reporting incorrect results. The participants further appreciated the fact that modern instruments are very expensive and that most rural schools cannot afford them as a result, many of the schools have outdated lab equipment and expired chemical reagents, which have greater chances of yielding inaccurate experimental results. This is consistent with Rani, Mundilarto, Warsono and Dwandaru (2019).

When examining the constraints of using VL, the lack of direct 'hands-on' experimentation emerged as a constraint. Similar observations were made by Deng et al, (2018). who pointed out that in a biology lab, for example, much is learnt from hands-on experience that the VL cannot offer such as slide preparation (i.e., slicing, staining, and creating a microscope slide of a sample). Likewise, Gyllenpalm, Rundgren, Lederman and Lederman, (2021), indicated that learners learn better when they measure, touch, feel, make charts, manipulate, draw, record data, and interpret data and make their own conclusions. This study, however, asked the question: Is there experiential evidence to show that learners are at a disadvantage when they do not experience a hands-on lab? This question was answered by Castelló et al (2020), who discovered that there was no statistical difference between the mean score marks of post-tests of two groups of learners exposed to virtual and 'hands-on' experimentation. The lack of 'hands-on' experiences, therefore, may not be a major constraint after all. In fact, in the context of the global COVID-19 pandemic, this study suggests that the lack of 'hands-on' in VL could indeed be a benefit in stemming the spread of the corona virus by not handling lab equipment that might be contaminated.

CONCLUSION

Several studies have underscored the benefits associated with teaching with the VL. However, the literature review revealed that research on the integration of VL as a teaching and learning tool in South Africa, particularly in rural and resource-constrained school contexts, is very scarce. This study contributes to the scanty literature on VL integration in South Africa. It investigates the integration of the VL and the opportunities and challenges associated with VL as a teaching and learning platform from rural science teachers' perspectives in South Africa. In particular, this study contributes to understanding rural science teachers' experiences in teaching with the VL in resource-poor secondary schools. Available literature in South Africa highlights the potential use of VL from university lecturers and students' perspectives and hardly from secondary school teachers.

This paper presents the enabling and constraining factors in using the VL to teach science from the perspective of teachers from rural and poorly resourced schools. Most teachers found that the VL has several features that enable the teaching and learning of science. Such features of the VL include affordability, a safe environment for conducting experiments and availability of up-to-date lab equipment and reagents. The results also show that the VL has some constraining factors, such as a lack of a 'hand-on' approach. However, notwithstanding the constraints of the VL reported by the teachers, the researchers believe that the VL can offer great opportunities to enhance the quality of laboratory experience in science teaching.

The results of this study suggest that fully understanding the enabling and constraining factors in using the VL to teach science is paramount to ensuring the successful adoption of the VL for teaching and learning. Thus, we suggest that further studies should be conducted to assess the possibilities of integrating VL in South African rural schools in terms of the current infrastructure and financial implications for the South African rural and resource-constrained schools. We hope these findings will open more knowledge to further research on this important topic by conducting this study.

RESEARCH IMPLICATIONS

This study has theoretically contributed to the existing literature on the use of the VL and has helped to raise the question of the importance of teaching with the VL in South Africa. The study was the first attempt on the integration of the VL in the South African rural and under-resourced secondary school context. Thus, the study will help rural science teachers understand the potential enabling and/or constraining factors of using the VL in their teaching. In addition, the study would be quite significant from a teachers professional development point of view. The Educational department can find out what support rural teachers need to effectively integrate the VL in their teaching even with limited infrastructure resources at their disposal.

LIMITATIONS

This paper presents the enabling and constraining factors in using the VL to teach science through scientific experiments. Yet, there were some limitations as follows: First, time constraints was one of the major impediments in this study. There was very limited time to conduct the study due to the schools' lockdown rules. Second, there was a lack of proper internet infrastructure in some of the research sites. The VL needed strong internet connectivity to work, and the poor internet connectivity in some of the selected schools in the study led to the slow and sub-optimal performance of the VL. Third, since the VL was a new platform and although a training workshop was conducted, teachers needed more time to first familiarise themselves with the platform, which could not happen due to the limitation of time. Last, the findings of this case study are only applicable to the context of the cases studied and cannot be generalised to a larger context. The study purposively used seven participants who might not have provided a wider view of the phenomenon of using the VL though the smaller sample was used to gain an in-depth understanding of the teachers' experiences with the VL.

FUTURE STUDIES

Based on the presented findings from this study, we suggest a further in-depth study of factors that may influence the successful integration of VL in the South African basic education sector. Such a study should attempt to bring to fore teachers' perspectives on the use of the VL for teaching and learning using a larger sample and on a large scale. The study can be further conducted on teachers of other districts as well as provincial or national level. The current study sample is the teacher participants working in different rural and under-resourced schools. The sample can be taken as learners. This

study can be used further to examine the acceptance of the VL by the learners. In addition, the results of this study suggest that fully understanding the enabling and constraining factors in teaching with the VL is paramount to ensuring the successful adoption of the VL for teaching and learning. Thus, future research will be worthwhile to assess the possibilities of integrating VL in South African rural schools in terms of the current infrastructure and financial implications for the South African rural and resource-constrained schools.

CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

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