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The integration of virtual labs into science education in Gauteng

Nhauro, Godwin

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The integration of virtual labs into science education in Gauteng

Godwin Nhauro

Supervisor: Prof René Pellissier

A research report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Management in the field of Digital Business

Johannesburg, 2021

ABSTRACT

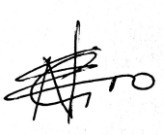
Research has shown that emerging digital technology-based innovations in education, including the integration of virtual labs in science education, have brought a significant paradigm shift in instructional delivery, providing far-reaching value and benefits regarding improving learning outcomes while providing learners with an excellent learning experience. The study investigated the extent of integration of virtual labs by teachers in supporting science education in selected South African public schools in Gauteng Province for improved learning outcomes. A quantitative survey was used to collect nominal and ordinal data from primary and secondary public school science teachers. Of the 207 (10% of Gauteng public schools) sampled schools, 135 responded. Nonparametric tests were used to analyse the data. The results show that the extent of integration of virtual labs in supporting science education is extremely low in terms of the percentage of teachers using the virtual lab in science pedagogy and the frequency of use. The results also show that the extent of use of virtual labs in teaching and learning differs according to the socioeconomic status of the community in which the school is located (school quintile ranking); thus, a higher percentage of teachers who use virtual labs were from affluent schools compared to under-resourced schools. In terms of improvement of the learning outcomes, the results of this study revealed a general improvement in the acquisition and long-term retention of science facts, skills, and knowledge; improved learning experience and learner achievements; and an improvement in learner interest in science, with the use of virtual labs.

KEYWORDS

Virtual reality, virtual labs, science education, learning outcomes, digital devices, scientific infrastructure

DECLARATION

I, Godwin Nhauro, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in Digital Business at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Name: Godwin Nhauro Signature: 

Signed at The Wedge, Randburg, Johannesburg

On the……. 26……. day of September…. 2022.

DEDICATION

This work is dedicated to my parents, family and friends for their unending support.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor Prof René Pellissier whose support, encouragement, guidance, comments, recommendations and overall insights in this field has been invaluable throughout this research study.

I would like to thank the Gauteng Department of Education, and its officials at provincial, district and school level for granting me the permission to conduct this study in their schools. A big thank you goes to all the teachers who were so generous with their time, data and digital gadgets in completing the online questionnaire survey.

My gratitude extends to the National Education Collaboration Trust for their contribution towards my tuition.

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LIST OF ACRONYMS

Acronym	Definition
DBE	Department of Basic Education
HSRC	Human Sciences Research Council
NEIMS	National Education Infrastructure Management System
STEM	Science, Technology, Engineering, Mathematics
TIMSS	Trends in International Mathematics and Science Study
VL	Virtual Laboratory
VR	Virtual Reality
Q	Quintile
NECT	National Education Collaboration Trust

CHAPTER 1. INTRODUCTION

The application of digital technologies is increasingly being integrated into almost all walks of life (Jaccard & Napal, 2014; Taufik et al., 2021). For over a decade, digital technologies have continued to disrupt and transform businesses across different industries, including education (Guan et al., 2020). The adoption and adaption of emerging digital technology-based innovation in education has brought a major paradigm shift in instructional delivery. The most applied type of digital technology in education is virtual reality (VR) (Bhattacharjee et al., 2018; Lee & Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020). A growing trend in VR-based methodologies in learning both in schools and higher learning institutions has been witnessed over the past decades (Guan et al., 2020; Lee & Wong, 2014; Penn & Ramnarain, 2019). Personalised student adaptive learning systems have been developed through VR-based teaching and learning methodologies. Such systems offer both personalised and collaborative interactive learning environments; auto-marking, scoring and evaluation systems (Makransky & Petersen, 2019). Thus, apart from offering a conducive and improved learning environment, most virtual learning systems remove the burdensome administrative duties from the teacher, one of the major causes why most teachers fail to cover the curriculum effectively. Failure to cover curriculum by teachers is prevalent in most South African schools, where teachers are reported as unable to finish the curriculum in time or not to cover higher-order cognitive skills according to Bloom's taxonomy (NECT, 2018). This matter has been aggravated by the effects of the national lockdown due to the Covid-19

global pandemic. School closures and rotational timetables led to severe learning losses, adversely affecting 13 307 830 learners across the country. Of the total number of affected learners, 92.7% (12 342 283) were from public schools, and 7.3% (590 282) were from private or independent schools (Soudien et al., 2022). The severity of the learning losses was noted to be worst in resource-constrained schools; Shepherd and Mohohlwane (2021) reported that foundation phase and intermediary learners in under-resourced schools lost 50-75% of a year of learning due to the Covid-19 pandemic. The education sector quickly shifted to a blended learning approach to ensure educational continuity. The shift was not a smooth sail at all.

With the emergence of digital learning-based technologies over the last three decades, the use of virtual labs in supporting science learning has been extensively advocated as a complementary pedagogic approach to foster 21st-century skills and competencies in learners and enhance their understanding of concepts (Guan et al., 2020; Lee & Wong, 2014; Penn & Ramnarain, 2019). However, its adoption and implementation took a slow pace until the advent of Coronavirus. As absurd as it may sound, Coronavirus was indeed the necessary evil needed to awaken and shake the education system out of its defiance of the adoption of technology-based teaching and learning approaches. The advent of the coronavirus pandemic has brought an exponential acceleration in the adoption and adaption of the use of digital technologies through multiple platforms by the schooling system, ensuring education continuity even in isolation.

Adoption and adaption of digital technologies in education by schools should not be viewed only as a short-term mitigation measure to combat Covid-19 disruptions but as the long-overdue much-needed approach to improve learning experience and outcomes. The value and benefits of using digital technologies in education are multitudinous. Empirical based studies (Akçayir et al., 2016; Frank and Kapila, 2017; Guan et al., 2020; Philippe et al., 2020; Roll & Wylie, 2016) have proven that digital technology-based teaching and learning methodologies, which include, among other virtual labs (Banet et al., 2019; Bhattacharjee et al., 2018; Estriegana et al., 2019; Lee & Wong, 2014; Penn & Ramnarain 2019; Wen et al., 2020), have great potential of improving learning outcomes while providing learners with an excellent learning experience.

However, the effective integration of digital technologies into education has its demands that most institutions of learning especially ordinary public schools, are still battling to meet. For instance, for effective implementation of virtual labs in science subjects first needs basic digital infrastructure and adequate learner and teacher resources to be in place and stable internet connectivity. Secondly will be teacher preparation (Padayachee, 2017) to necessitate the effective implementation of the digital technology-based methodologies during pedagogy. Teacher preparation is a multi-phase process, which requires, among other aspects, change of mindsets, attitudes, building new behaviours, instilling self-efficacy (Chen & Hu, 2020; Makransky & Petersen, 2019) in teachers towards the integration of digital technologies including use of virtual labs in education before training them on how to implement the methodologies.

1.1 Purpose of the study

The purpose of the study is to investigate the extent of integration of virtual labs in supporting science education in selected South African public schools for improved learning outcomes.

1.2 Background of the study

According to the South African Schools Act (SASA) of 1996, Act 84 of 1996, all learners have the right to quality basic education without discrimination (DBE, 2021). The responsibility of ensuring that this Act is realised is largely bestowed on the government, which means, among other things, the government has the responsibility of creating a conducive and enabling environment for every child to attain basic education. Enabling environment includes, among other things but is not limited to, the provision of resources and accessibility to basic education by every learner.

It goes without saying that the numerous challenges and issues facing the South African education system emanated from the apartheid era, which created unequal educational opportunities (including the uneven distribution of funding to schools) among learners based on the racial basis (DBE, 2013; Ogbonnaya & Awuah, 2019; van Dyk & White, 2019). That being said, the post-apartheid, democratically elected government of South Africa sought to eradicate the disparities in education created by the apartheid system by (1) promoting inclusive education programmes that seek to eliminate racial discrimination in education and (2) coming up with equitable school funding models (DBE, 2013 &

2021; van Dyk & White, 2019). In its endeavour to readdress the historical inequalities in education provision, the SA system came up with the quintile system. To this end, the Amended National Norms and Standards for School Funding (ANNSSF), as outlined in the SASA document, is a model of categorising schools into one of five quintiles based on their poverty score, of which Quintile 1 represents the poorest schools and Quintile 5 the least poor, in other words, the most affluent (DBE, 2013; Ogbonnaya & Awuah, 2019; van Dyk & White, 2019).

The poverty ranking of a school is based on the relative socio-economic status of the community in which the schools are geographically located (Ogbonnaya & Awuah, 2019). The rationale behind the school poverty ranking is that the schools serving poor communities, i.e., Quintiles 1 to 3, should receive a higher funding allocation relative to schools serving wealthier communities, Quintiles 4 and 5 (DBE, 2017; van Dyk & White, 2019). According to the annual report by the Department of Basic Education (2013), SASA has been amended to declare schools in poverty-stricken communities (Quintiles 1, 2 and 3) no-fee schools, whereas Quintiles 4 and 5 schools remain fee-paying schools (van Dyk & White, 2019) but still receive relatively low subsidies compared to Quintiles 1, 2 and 3 schools.

It is worth noting that the shortage of teaching and learning resources, which is prevalent in disadvantaged schools (Quintiles 1 – 3), results in poor quality of education (HSRC, 2019; TIMSS, 2020). Sadly, according to the DBE (2017) presentation on the poverty ranking of schools, roughly 86% of all South African

public schools fall under this category (Quintiles 1 – 3), catering for approximately 79% of all learners nationally.

1.2.1 *STEM education as the key driver of the country's digital economy*

Due to the ubiquitous connectivity through smart devices, computers and information technology systems, digital technology has, by default, become an integral part of the culture of today's global society (Jaccard & Napal, 2014). To this end, digital technology is changing the socio-economic landscape across the globe, giving rise and domination to certain companies within the global economy, for instance, Google, Netflix, Apple, and Facebook (Ho et al., 2020). Thus, Science, Technology, Engineering and Mathematics (STEM) skills have become a global game-changer, playing a pivotal role in driving sustainable economic development across industries through technological advancement (Ho et al., 2020). Hence, STEM jobs have become indispensable in the global labour market and are envisaged to remain the jobs of the future (Black et al., 2019) as the needs and demands of the global economy tend to depend heavily on STEM skills in driving a sustainable digital economy.

Sadly, several studies have reported shortages of STEM workforce from first world developed countries, including the United States of America (Caglar et al., 2015) United Kingdom (Kara et al., 2021), Australia (Kennedy & Odell, 2014; Panizzon et al., 2015) to third world developing countries. South Africa is no exception. However, for a nation to gain a competitive advantage in the global economy, grooming a STEM workforce is imperative. Thus, to ensure sustainable

economic growth in a competitive global market, initiatives targeting promoting the uptake of STEM subjects by learners in schools have become a priority in both developed and developing countries globally (Black et al., 2019; Panizzon, 2015).

STEM subjects are known to foster creativity, technological innovation (Coenen et al., 2021; Philippe et al., 2020; Kennedy & Odell, 2014), technology knowledge, digital literacy, and problem-solving skills in a more practical way and as resources allow, through hands-on experience. Moreover, these skills form the critical elements in driving the digital economy (Ho et al., 2020). Thus, to digitally transform the economy sustainably and competitively, it is a prerequisite that the workforce is equipped with such skills to meet the demands of today and the future workplace (Ho et al., 2020; Lavi et al., 2021).

However, fostering technological competencies and skills has faced its challenges, including a lack of interest in pursuing STEM subjects by learners and the general poor learner performance in STEM subjects (Caglar et al., 2015; Klentien & Wannasawade, 2016).

Considering the South African context, findings from numerous assessment studies done at the national, regional, and international levels indicated poor learner achievement in STEM subjects across all levels of the schooling system. Established by the International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS) is an international assessment study that compares learner's science

and mathematics achievement across the participating countries nationally since 1995 (HSRC, 2015) of which South Africa has been a participant since 1995. To interpret the results, TIMSS has five scale-score points benchmarks: 625–Advanced, 550-High, 475-Intermediate, 400–low and below 400–Not Achieved (HSRC, 2015).

According to the Human Sciences Research Council (HSRC, 2015), South Africa repeatedly underachieved in maths and science scores from 1995 to 2011, as shown in figure 1.

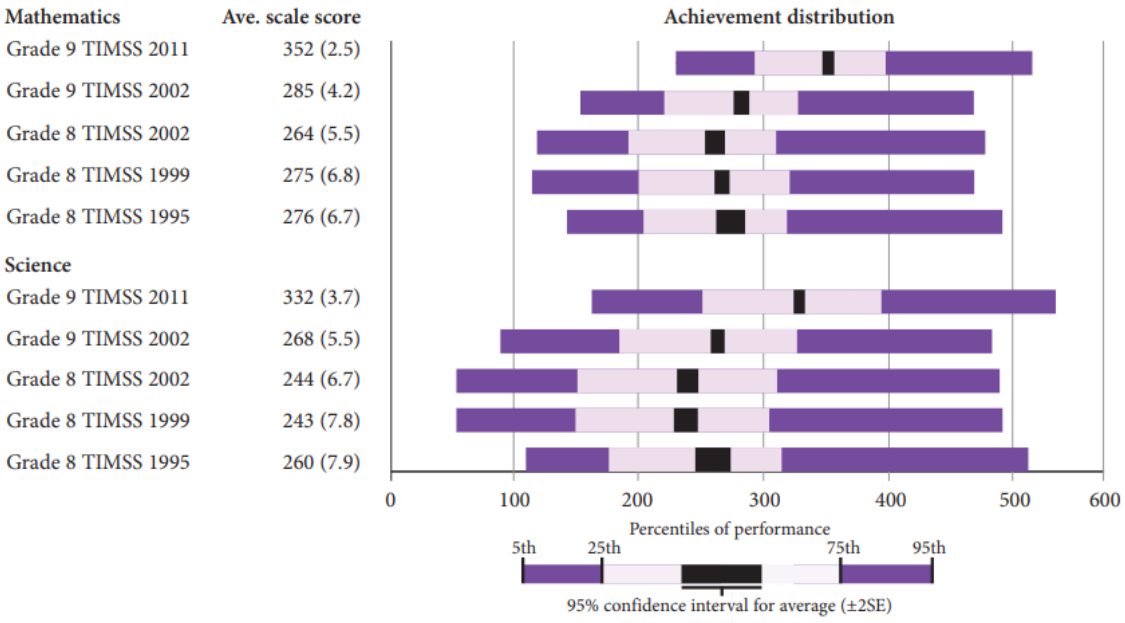


Figure 1: Grade 8 and 9 science and mathematics achievements for South African learners, from 1995 to 2011. Source**:** HSRC, (2015, p. 3)

The same trend shown in figure 1 is repeated in the 2015 and 2019 TIMSS results (HSRC, 2019; TIMMS, 2020).

1.3 Research problem

Several research studies have attributed poor learner performance in science subjects to numerous factors, including but not limited to lack of basic knowledge of science concepts, lack of scientific infrastructure (laboratories) in schools, and science concepts just too difficult for learners to grasp (Klentien & Wannasawade, 2016). The significance of learner exposure to inquiry-based learning, characterised by visual and practical involvement in learner achievement, especially in STEM subjects, cannot be overstated (Estriegana et al., 2019; Penn & Ramnarain, 2019). In the case of science subjects, the practical experience and visual learning are facilitated by the scientific infrastructure (laboratories) (Bhattacharjee et al., 2018; Penn & Ramnarain, 2019). Having stated that as a fact, the National Education Infrastructure Management System (NEIMS, 2021) reported an acute shortage of basic scientific infrastructure in 19 840 of 23 276 (80.07%) of the South African public schools. According to the Council for Scientific and Industrial Research (CSIR, n.d.), scientific infrastructure is a set of science resources such as laboratories, equipment, instruments, and lab consumables required for research, innovation, and experimentation.

Therefore, the absence of scientific infrastructures to support science education is one of the problems at hand in South African schools, implying that science pedagogy is predominantly abstract in most schools.

Problem and problem statement

The lack of scientific infrastructure in public schools has contributed to poor learner learning outcomes in science subjects over the years, with some schools, especially those located in remote areas (quantiles 1 – 3 schools), not offering science subjects in Further Education and Training (FET) band (grade 10 -12). This has resulted in fewer learners pursuing science-related fields at the tertiary level, hence the country's present acute shortage of STEM professionals.

Therefore, the research problem that informs this study is as follows:

The lack of scientific infrastructure in South African public schools contributes to poor learner outcomes in science subjects.

The research problem can be rephrased as the following guiding research question:

With the emergence of Virtual labs, an alternative to physical scientific infrastructure, HOW READY is the South African schooling system to leverage such digital technologies for better and improved learning?

1.4 Research questions

The research, therefore, seeks to address the following questions:

1. What are the constraints faced in the current methodologies used in science education?

2. To what extent are science teachers aware of the use of virtual labs in supporting science education?
3. What value do virtual labs have on science education?

1.5 Significance of the study

The findings of the study add to the existing body of knowledge on the use of virtual labs to support science education. Just like the findings from other studies such as Progress in International Reading Literacy Study (PIRLS) and TIMSS, that resulted in literacy (Early Grade Reading Study- EGRS) and numeracy (Early Grade Mathematics Project - EGMP) being made both national and DBE priorities, the findings of this study may open up a conversation/dialogue on the theme that can lead to further studies being done in this area. Furthermore, given the shortage of scientific infrastructures in most schools, especially in South Africa, the conversation may lead to the adoption of virtual labs as a better and cost-effective alternative to address not only the learning gaps due to the lack of traditional laboratories but also some of their limitations. Such dialogues and conversations may create awareness among teachers in South Africa and beyond on digital technology-based teaching and learning methodologies (VL) for a digital era and provide an opportunity for teachers to teach experimental science activities and "all" learners to actively participate in these experiments even remotely.

There is potential that the study may indirectly promote uptake of science by more learners in schools: a great majority of learners residing in remote areas with

great interest and potential to pursue STEM careers are denied the chance by their circumstances – because the nearby schools are not offering the STEM subjects due to lack of resources. More learners taking science subjects may reduce the shortage of STEM fields professionals in the country in the long run.

As supported by studies (Bhattacharjee et al., 2018; Lee & Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020), with the adoption of virtual labs in supporting science education, there is a greater potential for improving learning experiences and outcomes.

1.6 Delimitations of the study

i. Of the STEM subjects, the study focused only on science in selected primary and secondary schools.
ii. The research was conducted in Gauteng province only because the province has the most unequal school poverty ranking (DBE, 2021); thus, it represents all the other provinces as a worst-case example.
iii. Regarding research question 1 on the constraints faced in the current methodologies used in science education, the research focused on the availability of power supply, internet connectivity, and only laboratory and digital-based resources.

1.7 Definition of terms

Virtual lab: Burbules (2006, p. 37, in Makransky & Petersen, 2019) defined Virtual Reality as "a computer-mediated simulation that is three-dimensional, multisensory, and interactive so that the user's experience is "as if" inhabiting and acting within an external environment".

1.8 Assumptions

The research assumed the respondents understood the nature of the technologies discussed.

1.9 Chapter Outline

The background of this study, the context, the methodology employed, and the subsequent findings are covered in five chapters. Chapter 1 presents the introductory aspects of the study, which are the purpose of the study (section 1.1), the background of the study (section 1.2), the research problem (section 1.3), research questions (section 1.4), the significance of the study (section 1.5), delimitations of the study (section 1.6), the definition of terms (section 1.7), and assumptions (section 1.8).

Chapter 2 covers the review of related literature to the study and is organised into seven sections. Section 2.1 introduces the background discussion to the study, which, among other aspects, includes a description of the benefits of virtual reality-based learning in science education. Section 2.3 is a literature review of the first research question: constraints faced in the current methodologies used

in science education, followed by the corresponding proposition 1 (sub-section 2.3.1). In reviewing the second research question: the extent of science teacher awareness of virtual labs in supporting science education is discussed under section 2.4, followed by the second proposition under sub-section 2.4.1. Section 2.5 is a review of the literature with respect to the third research question: the value of virtual labs on science education, followed by the third proposition statement in sub-section 2.5.1. Finally, section 2.6 concludes the literature review based on the three research questions. For ease of accessibility sub-sections, 2.6.1 to 2.6.3 are the restated propositions. In the closing of chapter 2, section 2.7 presents the analytical framework, which is divided into two sub-sections, the theoretical framework (2.7.1) and the conceptual framework (2.7.2).

Chapter 3 is divided into ten sections; it opens with the research approach used in the study and the rationale behind the choice, section 3.1, which is then leads to section 3.2, which presents the research design and data collection methods employed, addressing why it is the appropriate method for the study and how it guides in answering the research questions. Section 3.3 discusses the population and population sample, which is further broken down into finer details on the sample and sampling method, sub-section 3.2.1. Section 3.4 describes how each section of the instrument (questionnaire) addresses specific issues raised in the research questions and literature. Section 3.5 describes the procedure taken for data collection. A summary of how the data was analysed and interpreted is elucidated in section 3.6. Finally, section 3.7, 3.8, 3.9 and 3.10 presents the

study's limitations, validity and reliability, respondents' demographic profile, and ethical considerations, respectively.

The following chapter, chapter 4, is divided into four sections and reports on the results coming from the study. The chapter opens with an introduction followed by a recap of how data was collected, analysed, and presented in the report (section 4.1). Next, the results pertaining to propositions 1, 2 and 3 are presented and narrated under sections 4.2, 4.3, and 4.4, respectively.

Chapter 5 presents a detailed discussion of the results. Section 5.1 introduces the chapter, giving a synopses approach to the chapter and the main aspects covered. Next, a synopsis of the demographics and response rates from the survey (section 5.2) is presented. Next, a detailed discussion on propositions 1, 2, and 3, which, among others, addresses the "so what" question and compares the findings of the study with findings from related studies and theories, is covered under sections 5.3, 5.4, and 5.5, respectively. Finally, the last section (5.6) summarises the key findings emanating from discussions from propositions 1, 2, and 3 outlining how the findings link or relate to each other, as well as highlighting any trends or patterns observed among the constructs across the three propositions relating to no-fee schools (quintiles 1-3) and fee-paying schools (quintiles 4 and 5).

The last chapter, chapter 6, opens with an introduction (section 6.1), recapping the value VL can offer to the education sector and the success conditions for the effective integration of VL in education. Next, sections 6.2, 6.3 and 6.4 present

the study's conclusion for research questions 1, 2, and 3, respectively. Lastly, sections 6.5 and 6.6 presents the recommendations and overall conclusion, respectively.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

The Fourth Industrial Revolution (4IR) brought about an exponential rise in digital innovations that gave birth to autonomous smart technologies, which are disruptive and pervasive in nature (Armstrong & Lee, 2021; Grodotzki et al., 2018). These digital technologies include, among others, but are not limited to, virtual reality, augmented reality, mixed reality, blockchain, artificial intelligence, and the Internet of Autonomous Things (IoAT) and are (i) simultaneously disrupting and transforming businesses across all industries at an exponential rate, and (ii) fundamentally changing the entire global society in the way people live, interact, work and learn (Armstrong & Lee, 2021; Estriegana et al., 2019; Grodotzki et al., 2018; Guan et al., 2020).

In the education industry, several studies have reported on the use of virtual reality (Banet et al., 2019; Bhattacharjee et al., 2018; Estriegana et al., 2019; Lee & Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020), augmented reality (Akçayir et al., 2016), mixed reality (Frank and Kapila, 2017), and artificial intelligence (Guan et al., 2020; Roll & Wylie, 2016) to support and improve teaching and learning. In addition, literature has shown that the application of such digital technologies in education has made a significant impact on content curation, packaging, the how it is relayed and ultimately used by students (Roll & Wylie, 2016).

Considering the ever-evolving digital technologies in education, science, technology, and engineering are the most adversely affected subjects, given that most laboratory equipment is becoming redundant and outdated to render the services that meet the current demand in a more logistically feasible manner (Frank & Kapila, 2017). Since virtual labs can be accessed through computer desktops, laptops, smartphones, and tablets anywhere, the combination of the present easy accessibility and the demonetisation of these digital gadgets and internet connectivity (Frank & Kapila, 2017; Heradio, 2016; Taufik et al., 2021), has made virtual labs a far much better alternative relative to traditional labs.

In this research, the focus is on the use of virtual reality to support science education.

2.2 Background discussion

2.2.1 *Virtual reality-based learning and its benefits in science education*

Burbules (2006, p. 37, in Makransky & Petersen, 2019) defined *Virtual Reality* as "a computer-mediated simulation that is three-dimensional, multisensory, and interactive so that the user's experience is "as if" inhabiting and acting within an external environment". Virtual Reality (VR) simulations can be categorised into three main types depending on the extent of immersion, thus the level to which the user's senses engage with the system (Lee & Wong, 2014; Lorusso et al., 2020; Makransky & Petersen, 2019).

The three types are low immersive, semi-immersive and fully immersive systems. The non-immersive, also referred to as low immersive, is the most common one, typified by desktop based-computer simulations in which the user can interact via the mouse, touch screen, keyboard, or controller (Lee & Wong, 2014). The second type is semi-immersive, in which the user is partially immersed, i.e., interacts with the 3D environments and still returns a connection with the physical surroundings (Lorusso et al., 2020). Finally, the fully immersive type, through the use of a head-mounted display (HMD), embodies the user inside the experience, allowing the user to actively engage with the 3D objects with some of the human senses such as vision, hearing and touch (Bhattacharjee et al., 2018; Lee & Wong, 2014; Lorusso et al., 2020).

VR technology in education has facilitated the evolution of physical laboratories to real-life learning contexts, virtual laboratories (VL), in which the user virtually interacts with the environment (Makransky & Petersen, 2019). Virtual reality is a significant technological innovation in science education, given that several research studies have indicated the fact that hands-on or practical experience in science learning plays a pivotal role in instilling scientific skills in learners and enhancing their understanding of science concepts (Bhattacharjee et al., 2018; Brinson, 2015; Estriegana et al., 2019; Penn & Ramnarain 2019).

Over and above offering science experience and possibilities of performing advanced experimentation, virtual laboratories also address the limitations and barriers of theory-based teaching and learning approach by fostering creativity, critical thinking, investigation, and innovation skills in learners by exposing them

to the practical process of designing solutions to real-life problems through computer-based simulations (Caglar et al., 2015; Kennedy & Odell, 2014; Philippe et al., 2020). Such VL offerings are not limited to education, but the application can be seen in various sectors like automotive, surgery, flight operations, and the clothing industry (Caglar et al., 2015).

Bhattacharjee et al. (2018) further indicated that this technology (VL) allows learners to explore and interact with complex science concepts and processes virtually and also offers a platform for experimentation of complex and dangerous experiments or processes that are difficult to control in physical laboratories, for example highly explosive chemical reactions. In addition to that literature (Bhattacharjee et al., 2018; Caglar et al., 2015; Estriegana et al., 2019; Lee & Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020; Philippe et al., 2020) outlines several other benefits of the integration of virtual laboratories into teaching and learning of science subjects. For example, virtual laboratories are reported to be highly engaging in early grades. They, therefore, have the potential of (1) fostering interest and the love for science in learners by making learning funny through the provision of a playful and adventurous learning experience, (2) developing their foundational scientific skills and knowledge by exposing them to basic science concepts (3) promoting creativity, critical thinking, problem-solving and innovation skills at an early age through science puzzles, games and simulations, (4) nurturing of a collaborative and teamwork spirit among learners, (5) rendering long term content knowledge retention in learners and (6) significantly improving learner performance and achievement.

All these attributes could potentially contribute to more learners taking STEM subjects and, in the long run, help in mitigating the STEM fields shortages.

As the old saying by Benjamin Franklin (Bhuvaneswari et al., 2020) goes, *'tell me, and I forget. Teach me, and I remember. Involve me, and I learn*', research by Bhattacharjee et al. (2018), Caglar et al. (2015), Estriegana et al. (2019), Lee and Wong (2014), Penn and Ramnarain (2019), and Wen et al. (2020) prove that meaningful learning occurs in an environment where learners are active participants in the learning process, especially through interaction with both spatial and visual representations. Thus, rather than leaving learners to their mere mindful imaginations of the subject matter or having them memorise concepts, virtual labs, through real experience simulations of concepts and content, do provide such ideal learning environments (that are based on visualisation), which are associated with an improved learning experience. Figure 2 below shows an illustration of various learning modalities and their corresponding long term information retention levels.

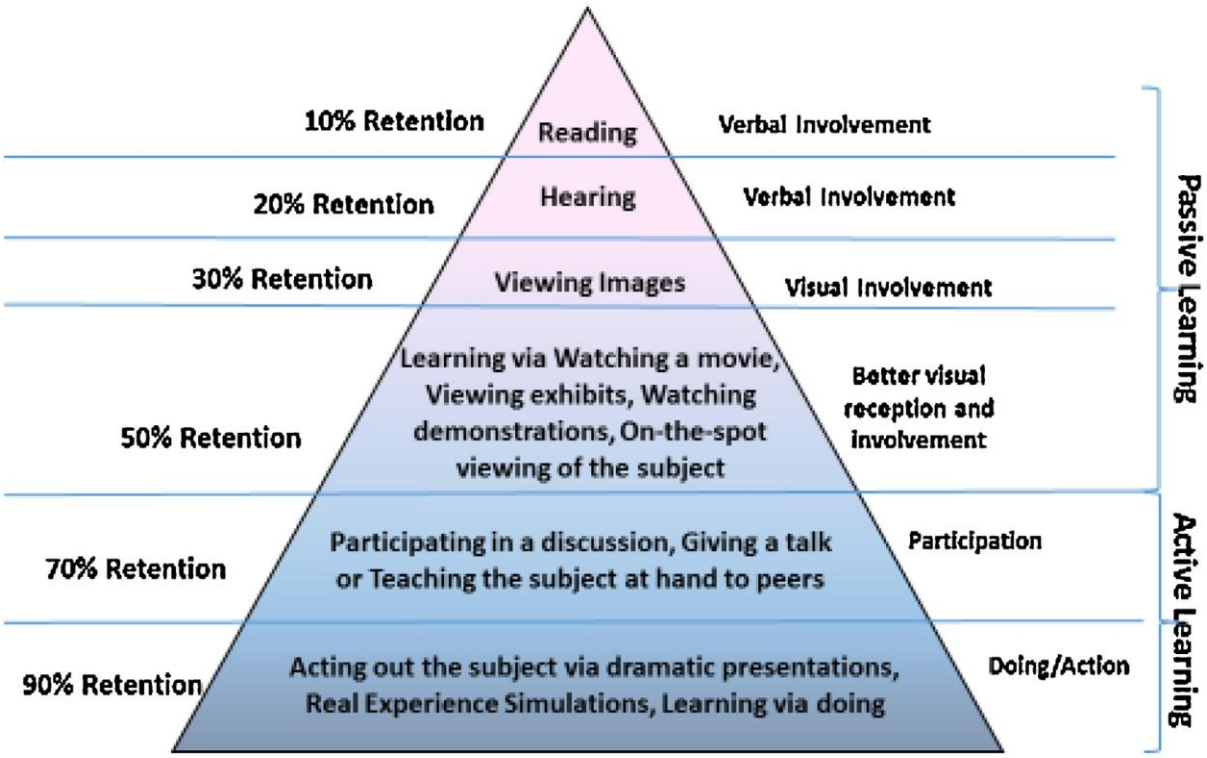


Figure 2: Learning modalities and their corresponding knowledge and skills retention levels. Source: Bhattacharjee et al. (2018, p. 237)

Figure 2 above shows the significance of adopting teaching and learning methodologies that promote active learner participation and personalised and collaborative interactive learning environments for learners to attain long term retention of science facts, skills, and knowledge.

Various studies (Bhattacharjee et al., 2018; Caglar et al., 2015; Estriegana et al., 2019; Heradio et al., 2016; Lee & Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020) presented several advantages that integration of virtual laboratories into teaching and learning of science subjects has over physical laboratories. These include among other, but are not limited to, (i) virtual labs are cheaper relative to physical labs both in terms of creation of the infrastructure, upkeep and

replenishment of consumables, (ii) with virtual labs, learners have access to up to date multi-million dollar cutting edge technology, which is constantly updated online at a very low cost, while with physical labs, schools cannot afford to consistently replace old dated instruments and equipment, (iii) virtual labs are much easier to use, does accommodate mistakes at no cost and without any negative impact, and allow learners to perform experiments several times without any cost implications on resources, which cannot be said with physical labs, (iv) virtual labs create both personalised and collaborative learning environments for learners; in that way, they can learn from their mistakes and most importantly, learning can always happen even in the absence of a teacher, (v) VL are accessible to learners 24/7 from anywhere, whereas in the case of physical labs, both the learner and teacher need to be at a fixed location/building, and (vi) learners have the privilege of performing harmful and health hazard experiments, most of which are forbidden in wet labs without any health risks.

2.3 Constraints faced in the current methodologies used in science education

Literature and several other articles have reported a severe shortage of teaching and learning resources in schools, especially those in impoverished communities (HSRC, 2019; Ogbonnaya & Awuah, 2019; van Dyk & White, 2019). The unavailability and inaccessibility of digital and scientific infrastructures are among the major constraints faced in science education (NEIMS, 2021 HSRC, 2019; Penn & Ramnarain, 2019). In support of this fact, Banet et al. (2019) pointed out that European secondary schools are not optimally benefiting from the value

derived from emerging technologies in education due to a lack of the appropriate teaching and learning resources. The use of conventional/traditional methods of teaching has left most learners bored and disengaged during classes, which has resulted in learners dropping out of their studies, approximately 15% in Europe, 25% in Spain (Banet et al., 2019) and a staggering 40% in South Africa (ZeroDropout, 2020). Though one could argue that there are diverse causes of learner dropouts, boredom, lack of interest, and disengagement remain on the top list (Banet et al., 2019).

Still, on the issue of resource shortage, Klentien and Wannasawade (2016) attributed poor learner performance in science subjects to several factors, including but not limited to lack of basic knowledge of science concepts, lack of scientific infrastructure in schools, and science concepts being too difficult for learners to grasp; all of which can be addressed through the implementation of an inquiry-based learning approach using virtual labs.

Wen et al. (2020) emphasised the importance of inquiry-based learning as a learning approach that (i) allows learners to engage actively and participate in the learning process through experiments, (ii) fosters scientific skills in learners such as investigations of and solving complex problems, critical thinking, creativity, and (iii) enhances learner understanding and long-term retention of complex science concepts. Traditionally, physical labs were the only source of inquiry-based learning in science education and hence their unavailability and inaccessibility to all learners adversely affect learner achievement in science subjects.

Given that building traditional laboratories for all schools involve considerable costs in terms of space, equipment, and upkeep (Frank & Kapila, 2017; Heradio, 2016), therefore the need for the adoption of virtual labs, which research (Bhattacharjee et al., 2018; Caglar et al., 2015; Estriegana et al., 2019; Lee & Wong, 2014; Penn & Ramnarain 2019; Wen et al., 2020) has advocated for, as a better alternative to traditional labs cannot be overemphasised. Moreover, leveraging the easy accessibility and affordability of digital gadgets (laptops, smartphones, and tablets) and internet connectivity (Heradio, 2016; Taufik et al., 2021) makes virtual labs better substitutes for brick-and-mortar labs.

2.3.1 *Proposition 1*

The constraints faced in the current methodologies used in science education are contributing to poor learner performance in science in South African public schools.

2.4 The extent of science teacher awareness of the use of virtual labs in supporting science education

A considerable colossal amount of research has been done over the last decades on the use of digital technologies (VL) in supporting teaching and learning in science education (Guan et al., 2020; Lee & Wong, 2014; Penn & Ramnarain, 2019). The outcomes of most of these studies point to the fact that not only is it feasible but also that it bears huge benefits to the learners, most of which have already been mentioned in this report. However, what value do such studies have to the schooling system if this knowledge does not filter down to the ultimate

implementors on the ground, i.e., the teachers. In this research, the questions to be addressed are (i) what percentage of the teachers in the system are aware of the availability of such digital technology (VL) for use in their classes and the value that can be derived from using it? (ii) to what extent are science teachers using this technology to support science learning? Not much has been found in the literature to answer these questions, not to say with certainty that it has not been done yet; there could be studies done on it.

2.4.1 *Proposition 2*

Teachers are not aware of the availability and value of virtual labs and hence are not using this technology (VL) in science education.

2.5 The value of virtual labs in science education

To determine the impact of virtual labs on student learning, Penn and Ramnarain (2019) performed a quasi-experimental study with the third-year pre-service science student teachers using a chemistry concept on acid-base reactions to (i) assess the effectiveness of virtual labs as an alternative way to leverage teaching and learning of chemistry concepts where there are no traditional laboratories and (ii) compare the impact of virtual labs against the traditional wet chemistry labs on student learning. The findings of the study revealed that the use of virtual laboratories aids in understanding chemistry concepts better than traditional laboratories.

Also, using a diagnostic assessment, pre and post-test, Lee and Wong (2014) came to the same conclusion as Penn and Ramnarain (2019) in their study, in which the use of virtual laboratories in science pedagogy yielded greater achievement in learning outcomes in students compared to the traditional teaching and learning approach. In their study, Lee and Wong (2014) investigated the impact of using virtual reality-based learning methodology on students with different spatial abilities using a concept in biology – dissection.

In a similar study by Wen et al. (2020), an interesting yet profound observation was made; the immediate pre and post-test results show no significant difference between the experimental and control groups. However, the delayed post-test provided a different trend, with the experimental group significantly outperforming the control group. In both studies (Lee & Wong, 2014; Wen et al., 2020), the experimental group interacted with virtual learning resources through a virtual lab, while the control group was subjected to a conventional classroom learning approach. The outcomes of the study by Wen et al. (2020) proved that virtual labs positively impact the students' scientific literacy and foster long-term retention of science facts, skills, and knowledge in learners, which are all basic critical elements in the learning process.

Using a different type of virtual lab, the immersive model, Bhattacharjee et al. (2018)'s research findings concurred with those of Penn and Ramnarain (2019), Lee and Wong (2014) and Wen et al. (2020) in which a non-immersive model was used. In the case of Bhattacharjee et al. (2018), the impact of the immersive virtual lab model on learning was investigated using grade 7 and 8 biology and

chemistry topics across three case studies, (i) learners without any learning disorders, (ii) learners with "Attention Deficit Hyperactivity Disorder (ADHD) and (iii) learners with "Audio Processing Disorder (APD)". In all three cases, the experimental group was exposed to virtual labs, whereas the control group was exposed to conventional teaching and learning methods. The outcome of the diagnostic tests shows a remarkable improvement in learner performance in the experimental group relative to the learners from the control group across the three case studies.

The findings from all these studies show that the students exposed to the virtual reality-based learning approach outperformed those subjected to the conventional teaching and learning methodology. Hence, given the value that virtual labs have on science education and the current poor learner performance in science in South African public schools, this research seeks to establish whether the schools are using this technology in science pedagogy. If they are using it, what could be the possible causes of not yielding the same value as studies have shown? A conversation for future research.

2.5.1 ***Proposition 3***

The use of virtual labs in science pedagogy improves learning outcomes, among other, learner achievements.

2.6 Analytical Framework

2.6.1 *Theoretical Framework*

The exponential rate of adoption and adaption of digital technology in learning by the schooling system has led to a paradigm shift from conventional pedagogy to new digital technology-based learning modalities, among others, conventional e-Learning, blended e-Learning and virtual e-Learning (Hammad et al., 2020; Kundi & Nawaz, 2010). The application of such e-Learning modalities is embedded in connectivism learning theory (Corbett & Spinello, 2020), cognitive and social constructivism, which includes, among other learning theories, inquiry-based teaching and learning theory, multimedia learning theory, technological pedagogical and content knowledge theoretical framework (TPACK), experiential learning theory, learning by doing theory and project-based learning theory (Blackburn & Hewitt, 2020; García, 2016; Hammad et al., 2020; Kundi & Nawaz, 2010).

Connectivism: the connectivism learning theory is based on several principles, which include the certitude that “learning is a process of connecting specialised nodes or information sources” (Corbett & Spinello, 2020). The theory is underpinned by four pillars of learning, namely: (i) autonomy, which refers to learners having the latitude to self-govern and direct their learning, (ii) connectedness: learners are connected to a network or nodes of information sources and that the learning process is both personalised and collaborative; (iii) openness: creating environments that facilitate exploration, innovation and

creativity in learners and (iv) diversity: learners are exposed to several sources of knowledge and do not have to be dependent on the teacher as the sole source of knowledge (Corbett & Spinello, 2020).

Thus, the connectivism learning theory recognises technology as a critical component in education that facilitates learning through connectedness among the stakeholders, thereby creating a learning community. Therefore, this study aligns with connectivism learning theory in driving the idea that the learning process can still occur outside a traditional brick-and-mortar classroom, through multiple platforms and in several forms, among other things, virtual labs, presenting learners with both personalised and collaborative learning environments.

Constructivism: Inquiry-based teaching and learning, multimedia learning theory, technological pedagogical and content knowledge theoretical framework (TPACK), experiential learning theory, learning by doing theory, and project-based learning theory are deep-rooted in both cognitive and social constructivism, which postulates that learners construct their knowledge through active engagements and experiences during the learning process (Akçayir et al., 2016, Hammad et al., 2020; Penn & Ramnarain, 2019; Wen et al., 2020). Thus, instead of being passive recipients of knowledge, learners get actively involved in acquiring knowledge and information by working collaboratively with their peers, teachers, and the broader community and individually through interactive learning (Hammad et al., 2020). Therefore, the learning theories mentioned above postulate that meaningful learning occurs in an environment where

learners actively participate in the learning process, primarily through interaction with spatial and visual representations. The notion above is supported by empirical studies that revealed that in science subjects, effective learning occurs when a learner is exposed to the context of the concept being taught, especially when dealing with abstract concepts that are hard to understand (Bhattacharjee et al., 2018; Caglar et al., 2015; Estriegana et al., 2019, Lee & Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020).

The idea of learners constructing their own knowledge through active engagement with multiple sources of information seems to cut across all the above-described educational learning theories. In the context of this study, this idea can be realised through the integration of virtual labs in science education. Thus, by leveraging virtual labs to support learning, learners are afforded a conducive learning environment that promotes active participation and personalised and collaborative interactive learning. Such learning environments afford learners the opportunity to (a) construct their own knowledge, (b) own and drive their learning, (c) be creative and develop critical thinking skills needed to solve complex problems, and (d) realise the practical relevance of science through an adventurous learning experience, thus fostering interest and the love for science in learners (Bhattacharjee et al., 2018; Caglar et al., 2015; Estriegana et al., 2019; Lee & Wong, 2014; Li et al., 2020; Makransky & Petersen, 2019; Penn & Ramnarain 2019; Philippe et al., 2020; Wen et al., 2020).

Therefore, this research is underpinned by a combination of the following theoretical frameworks, connectivism (Corbett & Spinello, 2020), cognitive and

social constructivism which includes, among other learning theories, inquiry-based teaching and learning, multimedia learning theory, technological pedagogical and content knowledge theoretical framework (TPACK), experiential learning theory, learning by doing theory and project-based learning theory.

The principles encapsulated in all the above-mentioned educational learning theories were considered in meeting several aspects of this study.

2.6.2 *Conceptual Framework*

This research was guided by four basic dimensions. Firstly, the constraints that schools are facing with the current science pedagogy focus on the challenges that science teachers face with the current teaching and learning methodologies and the barriers refraining them from adopting virtual labs as a complementary teaching and learning methodology. The second dimension was the extent to which science teachers are aware of virtual labs as a complementary teaching and learning methodology in science education. Coined together with the awareness aspect was to establish the extent of application of virtual labs in supporting science learning for teachers who are already aware of this digital technology, which is, in this case, the third dimension. Finally, the fourth dimension sought to find out the value that teachers and learners are reaping from integrating virtual labs into science pedagogy and compare their alignment to literature.

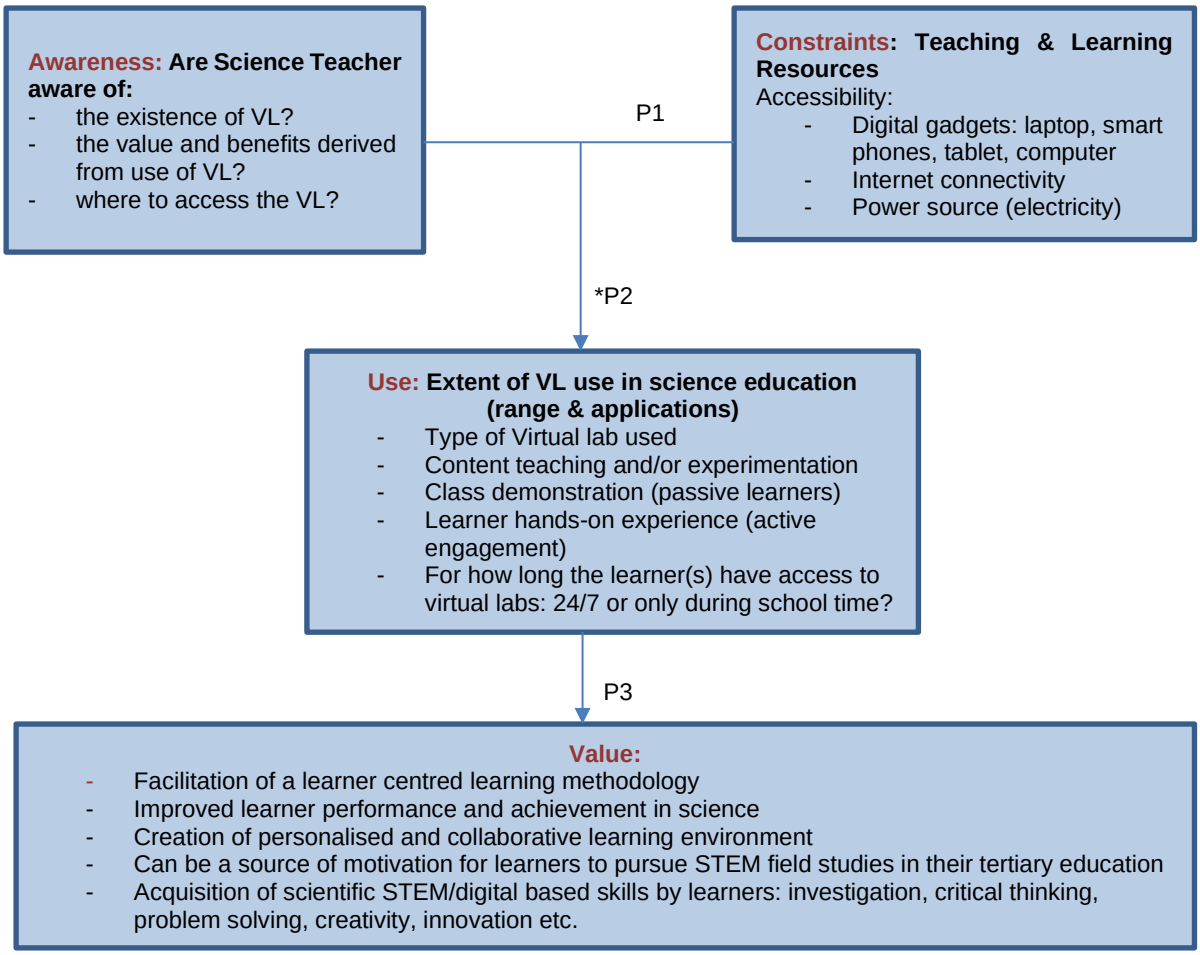


Figure 3: Conceptual Framework on the value of virtual labs in science education.

1. Assuming teachers are aware of the VL and have the necessary resources, then they are using the technology. (*P2 - proposition 2)
2. Assuming teachers are using virtual labs, then they are getting value from it. (P3)
3. The opposite outcome is assumed for all cases if the situation is reversed.

2.7 Conclusion of Literature Review

Based on the empirical evidence from the literature, virtual labs have far-reaching value and benefits in science education, which include, but are not limited to, the provision of a conducive learning environment that promote active learner participation (inquiry-based learning) and the creation of both personalised and

collaborative interactive learning environments for learners (Bhattacharjee et al., 2018; Lee & Wong, 2014; Makransky & Petersen, 2019). All of which lead to improved learning outcomes: acquisition and long-term retention of science facts, skills, and knowledge; an improved learning experience and learner achievements; and, above all, cultivating learner interest in pursuing STEM field subjects and careers (Bhattacharjee et al., 2018; Coenen et al., 2021; Kennedy & Odell, 2014; Lee and Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020). On the other hand, the unavailability and inaccessibility of such teaching and learning resources (labs) in schools pose an adverse impact on the country's economy (which in this era is largely dependent on digital technology, as discussed under the problem statement section of this report) in the long run, with poor learner performance being the immediately noticeable outcome and shortage of STEM job experts as the tip of an iceberg (Ho et al., 2020; Lavi et al., 2021).

CHAPTER 3. RESEARCH METHODOLOGY

Chapter 3 is divided into ten sections; it opens with the research approach used in the study and the rationale behind the choice, section 3.1, which is then followed by section 3.2, which covers the research design and data collection methods, addressing the suitability of the method for the study and how it guides in addressing the research questions. Section 3.3 discusses the population and population sample, which is further broken down into finer details on the sample and sampling method, sub-section 3.2.1. Section 3.4 describes how each section of the instrument (questionnaire) addresses specific issues raised in the research questions and literature. Section 3.5 describes the procedure taken for data collection. A summary of how the data was analysed and interpreted is elucidated in section 3.6. Finally, section 3.7, 3.8, 3.9 and 3.10 presents the study's limitations, validity and reliability, respondents' demographic profile, and ethical considerations, respectively.

3.1 Research approach

The study used a quantitative approach characterised by categorical data comprising nominal and ordinal data (Allanson & Notar, 2020; Chiang & Bock, 2022; Lin et al., 2022; Yuan et al., 2020). The rationale behind the choice of this approach is that the research questions are based on a measurable construct that can be best analysed by descriptive statistical means (Penn & Ramnarain, 2019; Taguchi, 2018), mainly using frequencies and percentages.

Quantitative studies allow tracking and monitoring changes in the variables of interest “over time through systematic, cyclical data collection” (Taguchi, 2018). Thus, longitudinal studies can be pursued focusing on the changes in (i) the constraints faced in the methodologies used in science education, (ii) the extent of science teachers’ awareness of the use of virtual labs in supporting science education and (iii) the value-driven from use of virtual labs in science pedagogy primarily improvements in learning outcomes among other, learner achievements. Thus, the findings of this study form the basis upon which other researchers can progressively do further research focusing on the same or related variables. Furthermore, findings from such studies can inform the Department of Basic Education of what is working, gaps and challenges faced by schools in integrating technology in pedagogy and could offer feasible mitigation measures to address the challenges and gaps.

The other advantage is that results from the quantitative studies can be generalised to the entire population (Rahman, 2017) since they are based on a larger representative sample randomly selected through a proportionate stratified random sampling method. Furthermore, the approach is less time-consuming when it comes to sampling and data analysis since it can use existing statistical software, for example, the Statistical Package for the Social Sciences – SPSS (Rahman, 2017).

However, the quantitative research paradigm has its shortfalls, including the failure to bring forth underlying contextual meanings, justifications and

explanations to the findings since it disregards the “respondents’ experiences and perspectives” (Rahman, 2017) on the matter.

3.2 Research design

Literature (Quon, 2018) noted two major types of surveys used by researchers, analytical and descriptive. A descriptive survey primarily seeks to answer the ‘what or how many’ related questions, identify trends, and determine the prevailing situation, among other aspects and hence “does not assume a hypothesis” (Quon, 2018). On the other hand, the analytical survey seeks to explain the relationship between variables mostly through testing the research hypotheses (Quon, 2018).

This study used a quantitative questionnaire-based survey to collect the data. A link to an online structured questionnaire instrument was sent to the respondents via email. The survey was selected mainly because this was descriptive research, seeking to collect quantifiable and measurable information (Ott & Longnecker, 2001) as dictated by the nature of the research questions. Thus, a more objective (measurable) and deductive approach was appropriate to address the research questions, hence the quantitative questionnaire-based survey method (Ott & Longnecker, 2001).

The questionnaire-based survey presents several benefits, such as (i) low cost while giving the researcher access to a large base of potential respondents instantly; which implies decisions can be made in a short time, and that data can be collected from multiple sources at once, (ii) high representativeness of the

population, (iii) data analysis can be done using statistical methods (Ahmed et al., 2022; Queirós et al., 2017), (iv) gives the researcher latitude to test many variables simultaneous, and (v) respondents can stay anonymous.

Notwithstanding the several benefits associated with the online survey method, this approach has its drawbacks, such as low response rate, ambiguity of the questions that can lead to biases in the results (Ahmed et al., 2022), and is impossible to do a follow up in case of non-responses or incomplete responses.

3.3 Population and sample

The population studied in this research are the Gauteng primary and secondary public schools from which science teachers were targeted. An updated list of all the registered Gauteng public schools retrieved from the DBE website was used for sampling. At the time of the study, the population size was N = 2 069 (see table 1 below for the breakdown per quintile–stratification). The sample selected for this study were science teachers and teachers teaching science subjects at the time of the study in selected schools across quintiles 1–5 in Gauteng province. The research sought to address questions on the current constraints faced in the science pedagogy, the extent of science teacher awareness of the use of virtual labs in supporting science education and the value of virtual labs on science education, which could be only best answered by a teacher who was teaching science at the time of the study or once taught science and is still in the school.

3.3.1 *Sample and sampling method*

Probability sampling was used in this study because, unlike non-probability sampling, probability sampling ensured that each sample (school) within a population had an equal chance of being chosen (George, 2021). Furthermore, since the population from which the samples were taken is highly heterogeneous, from the poorest schools to the most affluent schools, to ensure that every quintile (strata) is proportionally represented, a proportionate stratified random sampling method was used. As noted by George (2021) and Ott and Longnecker (2001), in cases where the population is heterogeneous, stratified sampling guarantees that the sample is representative of the population since each of the categories is represented.

On the other hand, the non-probability sampling technique is not based on randomised selection but rather on judgement and personal discretion, making it subjective. Unfortunately, the findings from this sampling method cannot be generalised (George, 2021). For these reasons, probability sampling was chosen over the non-probability sampling method.

The South African public schooling system has already segregated schools into homogenous groups (strata) using a poverty ranking system known as the quintile system (DBE, 2017; van Dyk & White, 2019); see table 1 below for the quantile distribution of schools in Gauteng.

In the table below, N represents the total number of primary and secondary public schools in Gauteng province (N = 2 069). Per each quantile, 10.0% of the total

schools were randomly sampled (strata). A random number table was used to select the schools per quantile randomly. The sample size (n) is the total number of schools sampled across the quintiles (Q1 – Q5); thus, n = 207 schools. One science teacher per school was sampled, and therefore the number of schools is equal to the number of teachers sampled.

Table 1: Stratification applied to Gauteng public schools according to poverty ranking.

Quintile	Poorest				Most affluent	Total
	Q1	Q2	Q3	Q4	Q5	
% Schools per Q	13.2%	12.5%	20.2%	23.1%	30.9%	100%
# Schools per Q	274	259	418	478	640	N = 2 069
Sample size	27	26	42	48	64	n = 207

Source: Department of Basic Education, Republic of South Africa, 2021

3.4 The research instrument:

The questionnaire had four sections (see appendix A):

i. Section A: collected data on school backgrounds such as the quintile under which the school fall, whether it is a primary or secondary school and the phase the teacher teaches.

ii. Section B - Addressed research question 1: The constraints faced in the current methodologies used in science education (Delimitations: Research only focused on the availability of power supply, internet connectivity, and laboratory and digital-based resources).

iii. Section C - Addressed research question 2: The extent to which science teachers are aware of the use of virtual labs in supporting science education.

iv. Section D - Addressed research question 3: The value derived from using virtual labs in science education.

The instrument was developed partly based on the TIMSS instrument, which assesses the availability of resources in schools and at home (for learners) in its studies.

3.5 Procedure for data collection

A formal application requesting permission to conduct research in the Gauteng schools was submitted to the Gauteng Department of Education (GDE). The GDE has a structured research request form that applicants must complete and submit at least two months prior to the research start date. After the approval from GDE, in observance of the POPI Act, a list of sampled schools was submitted to the Gauteng Departmental official and all the districts for dissemination of the online structured questionnaire link to the teachers. Since the questionnaire did not request for district, school and personal details, all responses were anonymous.

Emailing have been chosen as the most viable options over face-to-face due to the Covid- 19 pandemic restrictions.

3.6 Data analysis and interpretation

A descriptive statistics approach was used to analyse the data with the aid of the SPSS software (Penn & Ramnarain, 2019). The data collected is categorical data

comprising both nominal and ordinal data. Nominal and ordinal data sets are a group of nonparametric variables. The major characteristics that define nominal data are that it is unordered and can be classified into mutually exclusive groups within a variable, implying only equality or identity comparisons are relevant; while ordinal data cooperate in some form of order or ranking (Allanson & Notar, 2020; Chiang & Bock, 2022; Lin et al., 2022; Yuan et al., 2020). Thus, with ordinal data, both "equality comparisons (is one value equal to another) and inequality comparisons (is one value less than or greater than another) are allowed, though it may not be possible to quantify the difference between values" (Yuan et al., 2020. P. 1 499).

Statistically, due to their categorical nature, both nominal and ordinal data cannot be evaluated by parametric tests (Chiang & Bock, 2022) such as means, standard deviation, variance, and regression. Furthermore, since the data do not have numerical magnitude or size, parametric tests are considered meaningless or somewhat inconclusive, given that most of the parameters “(e.g., mean and standard deviation) are invalid for descriptive statistics” if the data is on nominal and ordinal scales (Ulf, 2004). In this case, the data is best analysed and evaluated using nonparametric statistics, primarily frequency tables, percentages (Chiang & Bock, 2022), pie charts, and graphs.

Hence in this study, only nonparametric tests (frequency tables, pie charts and bar graphs) were used to analyse and evaluate the data.

3.7 Limitations of the study

This study is, however, subject to several methodological limitations. *Firstly*, only Gauteng schools registered with the DBE were selected for this study.

Secondly, the survey response rate was relatively lower than anticipated. Of the study sample size (n=207), 135 teachers responded, giving a 65.2% response rate. Low response rates have been observed to be a common trend with the online survey approach. Rice et al. (2017) pointed out that roughly 10 % of the participants quit the survey after going through the preamble or instructions, while 10-15% quit halfway through. Literature also noted that the participant dropout rate increases with an increase in the survey length, with fifteen-minute or longer surveys likely to "retain only 50% of participants" (Rice et al., 2017). Overall, a low response rate can introduce nonresponse bias which could compromise the overall interpretation of the results and make it difficult to generalise the study findings to the entire population (Rice et al., 2017).

Thirdly, by virtue of the nature of the methodology used in this study, it is not feasible to conduct a longitudinal study since respondents were completely anonymous. However, longitudinal studies could provide information on the changes in variables over time.

Lastly, the fact that the study relied on self-reported data that could not be independently verified poses the danger of bias, such as attribution, the tendency to attribute positive outcomes or experiences to oneself, and the possibility of exaggeration (Rice et al., 2017).

3.8 Validity and Reliability

The concept of validity seeks to establish the accuracy to which collected data addresses the research questions (Heale & Twycross, 2015). Thus, a means to ascertain that the study instrument is accurately measuring what it intended to measure (Taherdoost, 2016).

Types of validity include content, face, construct, and criterion validity (Heale & Twycross, 2015; Taherdoost, 2016). Content validity measures the degree to which the instrument of measurement comprehensively covers all the content areas as per the variables or constructs being studied, whereas face validity involves consulting experts in the field to solicit their views on whether the instrument adequately captures the intended concepts (Heale & Twycross, 2015; Taherdoost, 2016).

In this study, to ensure content and face validity, a thorough literature review was conducted to ensure all the relevant items to each construct domain were covered in the survey instrument in a clear and unambiguous manner (Taherdoost, 2016). Furthermore, the questionnaire was well formatted, free of spelling mistakes and other errors, and questions were pitched at the right level of difficulty for the targeted respondents (science teachers) where necessary definitions of certain terms were given on the instrument to prevent respondents from assuming what the terminology meant or using their own interpretation.

Regarding construct validity, the researcher developed relevant metrics and indicators that comprehensively measure the research constructs based on the

appropriate literature. Construct validity is “how well you translated or transformed a concept, idea, or behaviour that is a construct into a functioning and operating reality, the operationalization” (Taherdoost, 2016).

The survey instrument was reviewed by a combination of the science curriculum, assessment, and digital learning specialist to assess and evaluate its suitability, clarity, and appropriateness in addressing the research questions (Bawa’aneh, 2021). Among the specialist was the research supervisor. The instrument was then revised accordingly, following the feedback from experts. Ultimately, the instrument was piloted through selected respondents to assess its effectiveness in practice, and further revisions were done accordingly.

Reliability refers to the stability and consistency of a measure (Heale and Twycross, 2015). In this study, the internal consistency of the survey instrument constructs was found to be high, α = 0.92, as determined by calculating Cronbach’s alpha. According to literature, the survey instrument used in this study was found to be highly reliable; a Cronbach’s alpha value of 0.90 and above means excellent reliability (Taherdoost, 2016).

3.9 Demographic profile of respondents

The instrument was not designed to collect data on the demographic profiles of respondents (the data was of no relevance to the study). The respondents could be of any age, race, and gender as long as they were teaching science subjects in the selected schools.

3.10 Ethical considerations

Participants were asked to confirm their consent before completing the online survey questionnaire. Their responses are kept confidential, and their identities (names and the name of the schools) anonymous. The questionnaire did not ask for any personal or sensitive information, nor were the respondents paid for participating in this study. The respondents were also informed beforehand that they could withdraw at any time or choose not to answer any question if they did not want to. All data gathered is preserved in a password protected computer for further future studies by other researchers. For more information on participant information and consent (agreement form), please refer to appendix B and C, respectively.

Table 2: Consistency table: research questions, propositions, data collection and data analysis

RQ #	Research Question	Proposition #	Proposition	Data collection detail	Data analysis method
1	What are the constraints faced in the current methodologies used in science education?	1	The constraints faced in the current methodologies used in science education are contributing to poor learner performance in science in South African public schools.	Survey instrument questions 1.1 - 1.3.1, Likert statements: 1.3.2 (a-e) and 1.3.3 (a-f)	Descriptive statistics: Frequency tables, percentages, graphical techniques (pie charts, bar graphs)
2	To what extent are science teachers aware of the use of virtual labs in supporting science education?	2	Teachers are not aware of the availability and value that can be derived from virtual labs and hence are not using this technology (VL) in science education.	Survey instrument questions 2.1 - 2.5; 2.7 – 2.8 Questionnaire Likert statement 2.6 (a-h) and 2.9 (a-j)	
3	What value do virtual labs have on science education?	3	Use of virtual labs in science pedagogy improve learning outcomes among other, learner achievement.	Likert statements: 3.1 (a-l)	

CHAPTER 4. PRESENTATION OF RESULTS

4.1 Introduction

A quantitative survey was used to collect the data. In adherence to the POPI Act regulations, an online structured questionnaire instrument was sent to the respondents via the Gauteng provincial and district officials. Since the population from which the samples were taken is highly heterogeneous, from the poorest schools (quintile 1) to the most affluent schools (quintile 5), to ensure that every quintile (strata) is proportionally represented, a proportionate stratified random sampling method was used, to ensure each of the categories was represented.

The questionnaire had four sections:

i. Section A: collected data on school backgrounds such as the quintile under which the school fall, identified whether it is a primary or secondary school, and noted the phase the teacher teaches.
ii. Section B - Addressed research question 1: The constraints faced in the current methodologies used in science education (Delimitations: Research only focused on the availability of power supply, internet connectivity, and laboratory and digital-based resources).
iii. Section C - Addressed research question 2: The extent to which science teachers are aware of the use of virtual labs in supporting science education.
iv. Section D - Addressed research question 3: The value derived from using virtual labs in science education.

As mentioned earlier in the methodology section, the study collected both nominal and ordinal data, which cannot be evaluated by parametric tests (Chiang & Bock, 2022) such as means, standard deviation, variance, and regression. Hence, only nonparametric tests (frequency tables, pie charts, and bar graphs) were used to analyse and evaluate the data.

Analysis and Results Presentation

The results are presented in the following sequence: per each proposition, based on the research survey question, a table or graph is given followed by a narrative on the information presented in the table or graph.

4.2 Results pertaining to proposition 1

Proposition 1: *The constraints faced in the current methodologies used in science education are contributing to poor learner performance in science in South African public schools.*

This section is divided into four sub-sections as follows:

- availability of power supply at schools,
- accessibility of internet in schools,
- availability of science laboratory and laboratory resources in school, and
- availability of digital resources to support teaching and learning in schools

Do you have a power supply at your school?

Regarding the availability of power supply at schools, 98.5% (133) of the respondents indicated that they do have a power supply source at their schools, and only 1.5% (2) indicated that they do not have power supply. However, there is a slight misalignment in the aforementioned findings when compared with the Department of Basic Education's data on the number of Gauteng schools with power supply. According to NEIMS Report (2021), all schools (2 074) have power supply. However, the Report indicates that 105 schools have an unreliable power supply, with 39 using generators, and six schools using solar as a power supply source. It is most likely that the 1.5% (2) of the respondents who indicated that they do not have power supply could be the ones using generators or solar as a power supply source.

Please indicate internet accessibility at your school

To answer the survey questions on the accessibility of the internet in schools, respondents were asked to indicate internet accessibility at their school. Analysed data from the survey is presented in Table 3.

Table 3: Summary of the status of internet accessibility in 'no fee schools' (Q 1-3) and 'fee-paying schools' (Q 4 and 5)

Question	Quintile 1 - 3				Quintile 4 and 5				Unidentified Quintile				Total			
	Yes	No	I don't know	N/A	Yes	No	I don't know	N/A	Yes	No	I don't know	N/A	Yes	No	I don't know	N/A
Do you have internet connectivity at your school?	26	24	1	0	71	2	1	0	8	1	1	0	105	27	3	0
Is the internet connectivity stable and reliable?	9	9	12	21	34	10	27	3	8	1	1	0	51	20	40	24
Is the internet speed fast enough to support use of digital technology during teaching and learning?	5	13	11	22	48	8	17	1	8	2	0	0	61	23	28	23
The internet is only for the School Management and Administrative staff	16	18	1	16	11	57	3	3	3	7	0	0	30	82	4	19
School provides internet access to support teaching and learning.	13	26	2	10	55	8	10	1	7	3	0	0	75	37	12	11
School provides internet access to learners to support learning.	12	31	1	7	51	12	8	3	3	7	0	0	66	50	9	10

The results summarised in table 3 are narrated below.

Do you have internet connectivity at your school?

As shown in Table 3, of the 105 (77.8%) respondents who indicated that they have internet connectivity at their schools, the majority, 71 (67.6%), are from quintile 4 and 5 schools, while 26 (24.8%) and 8 (7.6%) are from quintiles 1- 3 schools and unidentified quintiles respectively. In comparison, of the total number of respondents from 4 - 5 schools, 95.9% reported that they have internet access, while quintiles 1- 3 schools, only 51.0% indicated that they have access to the internet.

Is the internet connectivity stable and reliable?

Overall, 51 (37.8%) of the respondents (teachers) indicated that they have stable and reliable internet connectivity; 20 (14.8%) reported that the internet connectivity is not stable; 40 (29.6%) do not know whether the internet is stable and reliable or not; 24 (17.8%) says it is not applicable. Thus, a considerable number of science teachers, 64 (47.4%) indicated the "I do not know and Not applicable" category, seem not to be concerned with the use of internet-based materials for teaching and learning, of which the majority, 51.6% are from quintiles 1-3 schools.

Is the internet speed fast enough to support the use of digital technology during teaching and learning?

With regards to whether the internet speed is fast enough to support the use of digital technology during teaching and learning, 61(45.2%) of all the respondents confirmed yes, of which the majority, 78.7% are from quintiles 4 and 5 schools and only 8.2% from quintiles 1 -3 schools. Thus, of the total respondents from quintiles 1 – 3, the majority of schools, 90.2%, do not have internet speed that can support the use of digital technology during teaching and learning compared to 35.1% from quintiles 4 and 5 schools. Astonishingly, a staggering 61 (45.2%) of the total respondents seem not to be concerned with internet-based technology during teaching and learning, of which the majority, 54.1% are from quintiles 1 – 3 (64.7% of the Q 1-3 schools' respondents).

The internet is only for the School Management and Administrative staff.

As shown in Table 3, 82 (60.7%) of the respondents indicated that the internet is not only for the School Management and Administrative staff, of which the majority, 69.5% (57), are from quintiles 4 and 5 schools. On the other hand, of the schools, 30 (22.2%) reported that the internet is only for the School Management and Administrative staff; the majority, 53.3%, are from quintiles 1-3.

School provides internet access to support teaching and learning.

More than half of the schools, 55.6% (75), provide internet access to teachers to support teaching and learning; quintiles 4 and 5 account for the greater proportion, 73.3%, while quintiles 1-3 schools contribute only 17.3%.

School provides internet access to learners to support learning.

As presented in Table 3, slightly over half of the schools, 51.1% (69), are not providing internet access to learners to support the learning processes. Of the 48.9% (66) of the schools that provide internet access to learners to support learning, the majority, 77.3%, are from quintiles 4 and 5 schools, with only 18.2% coming from quintiles 1 – 3 schools.

The objective of the next section was to explore the availability of the necessary scientific and digital infrastructure to support science education in schools.

Availability of science laboratory and laboratory resources in school

Figure 4 compares the availability of laboratories, either physical buildings or mobile labs, in quintiles 1 -3 schools and quintiles 4 and 5 schools.

Is there a laboratory (either a physical building or a mobile lab) at your school?

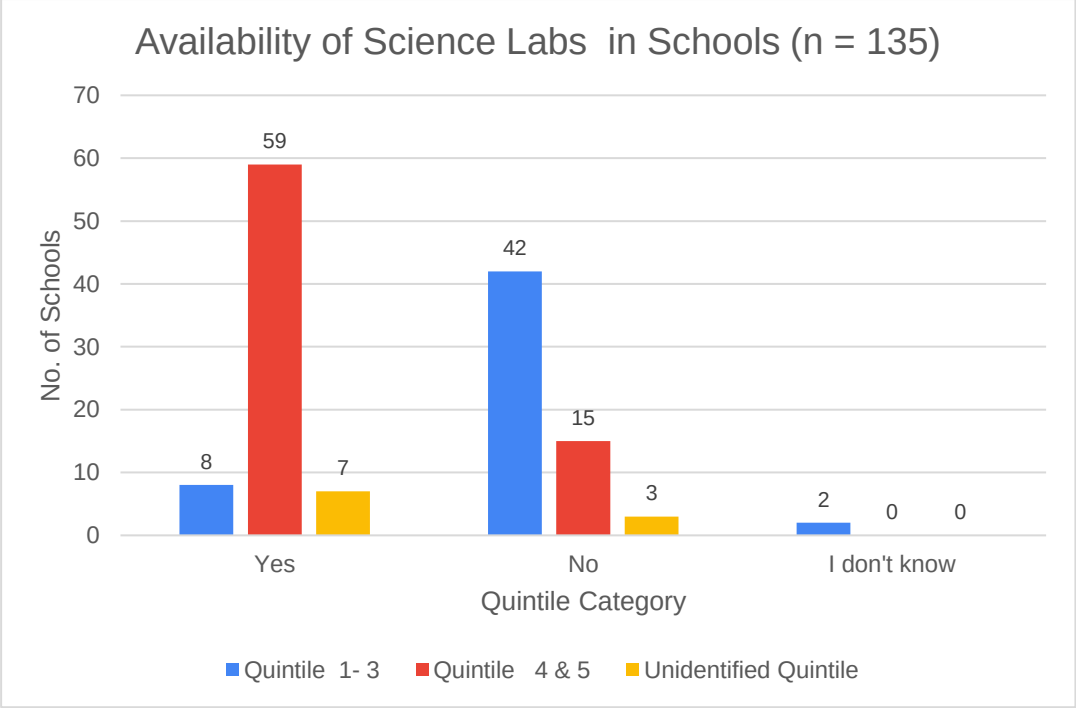


Figure 4: Summary of the availability of science laboratory in 'no fee schools' (Q 1-3) and 'fee-paying schools' (Q 4 and 5)

As illustrated in Figure 4, slightly above half, 54.8% (74) of the surveyed schools have laboratories - either a physical building or a mobile laboratory. Of these, 79.7% are from quintiles 4, and 5 schools and 10.8% are from quintiles 1 -3 schools. Of the remaining 61 (45.2%) schools, 44.4% indicated that they do not have laboratories at their schools, of which 70.0% of them fall under quintile 1-3 schools; and 3.2% said they do not know whether their schools have laboratories or not.

Table 4 provides the summary of the responses on the availability of laboratory resources to support teaching and learning in schools.

Please rate the availability of each item of laboratory resource or support personnel at your school by selecting the relevant response. Scale 1 = Never; 2 = Seldom; 3 = Usually; 4 = Always; 5 = I don't know; 6 = N/A.

Table 4: Summary of the availability of laboratory resources to support teaching and learning in no fee schools (Q 1 – 3) and fee-paying schools (Q 4 and 5)

Question	Quintile 1 – 3 Schools						Quintile 4 & 5 Schools						Unidentified						Total					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Apparatus for science experiments	15	17	6	1	3	9	1	26	35	10	0	2	0	0	6	3	1	0	16	43	47	14	4	11
Chemicals for science experiments	23	10	5	1	3	9	8	33	24	7	0	2	1	0	5	3	1	0	32	43	34	11	4	11
Protective clothing for science experiments	28	2	1	2	5	13	38	14	7	4	5	6	3	4	1	1	1	0	69	20	9	7	11	19
Lab safety resources (e.g., fire extinguishers)	18	4	4	11	3	11	9	4	11	46	0	4	1	1	3	4	1	0	28	9	18	61	4	15
Suitable laboratory assistant(s)	34	3	1	0	3	10	54	10	4	2	0	4	5	3	0	1	1	0	93	16	5	3	4	14

Outlined below is the narrative of the analysis on the availability of laboratory resources to support teaching and learning in no-fee schools (Q 1 – 3) and fee-paying schools (Q 4 and 5) based on Table 4.

Availability of apparatus and chemicals for science experiments in schools

Of the 135 respondents, 11.9% (16) and 23.7% (32) of them reported that they never had apparatus or chemicals for science experiments in their schools respectively; of which the majority (93.8% and 71.9% respectively) of these schools are quintile 1-3 schools. On the other hand, 31.9% (43) indicated that they seldomly have both apparatus and chemicals for science experiments, 34.8% indicated that they usually have chemicals for science experiments, of which the majority (74.5%) are from quintiles 4 and 5, and 25.2% (34) indicated that they always have chemicals for science experiments, of which 70.6% are quintiles 4 and 5 schools.

Availability of suitable laboratory assistant(s)

Most of the schools, 68.9% (93) of the schools reported that they never had laboratory assistants, while merely 3.0% (4) indicated that they always have laboratory assistants.

Table 5 summarises the survey results on the availability of digital resources to support teaching and learning in schools.

Please indicate the availability of each of the listed below digital resources at your school by selecting the relevant response.

Table 5: Summary of the availability of digital resources to support teaching and learning in no fee schools (Q 1 – 3) and fee-paying schools (Q 4 and 5

Question	Quintiles 1 - 3			Quintiles 4 & 5			Unidentified			Total		
	Yes	No	I don't know	Yes	No	I don't know	Yes	No	I don't know	Yes	No	I don't know
School has computers/laptops for teacher use	19,0	32,0	0,0	69,0	5,0	0,0	8,0	2,0	0,0	96,0	39,0	0,0
School has projectors for lesson delivery	8,0	36,0	7,0	48,0	6,0	20,0	7,0	3,0	0,0	63,0	45,0	27,0
Learners share computers	23,0	28,0	0,0	59,0	15,0	0,0	4,0	6,0	0,0	86,0	49,0	0,0
Each learner is allocated her/his own desktop computer	1,0	49,0	1,0	4,0	67,0	3,0	2,0	8,0	0,0	7,0	124,0	4,0
Each learner has/is allocated her/his own laptop/tablet	2,0	49,0	0,0	5,0	68,0	1,0	1,0	9,0	0,0	8,0	126,0	1,0
Each learner has a smart phone used for digital learning	2,0	37,0	12,0	26,0	16,0	32,0	0,0	9,0	1,0	28,0	62,0	45,0

Below is the narrative of the analysis on the availability of digital resources to support teaching and learning in no-fee schools (Q 1 – 3) and fee-paying schools (Q 4 and 5) based on Table 5.

The school has computers/laptops for teacher use and projectors for lesson delivery.

Overall, most of the schools, 71.1% (96) do have computers/laptops for teacher use, of which the bulk of them, 71.9%, are quintiles 4 and 5 schools. Of the 28.9% of the schools that indicated that they do not have computers/laptops for teacher use, the majority of them, 82.1%, are quintiles 1-3 schools. Less than half of the schools, 46.7% (63), have projectors for lesson delivery, of which the majority, 76.2%, are quintile 4 and 5 schools and only 12.7% from quintile 1 - 3 schools.

Learners share computers

In total, 63.7% (86) of the schools indicated that learners share computers, 68.6% are from quintiles 4 and 5 schools, and 26.7% are from quintiles 1 – 3 schools.

Leaners possess the necessary digital devices to support learning

Overall, 20.7% (28) of the teachers across all quintiles indicated that their learners possess digital devices for learning, of which only 7.1% (2) are from quintiles 1 -3 schools, compared to 92.9% (26) from quintiles 4 and 5 schools.

The next section presents the results under the second research question, which sought to establish the extent to which science teachers are aware of and are using virtual labs to support science education.

4.3 Results pertaining to proposition 2

Proposition 2: *Teachers are not aware of the availability and value of virtual labs and hence are not using this technology in science education.*

This section is divided into five sub-sections as follows:

- level of teacher confidence in using technology in class,
- teacher's awareness of virtual labs and accessibility to virtual lab teaching and learning materials,
- the extent of use of virtual labs (VL) in science education by the teacher,
- learner access to digital devices (computers, tablets, smartphones) during class, and
- the extent of learner engagement in digital learning through virtual labs.

Level of teacher confidence in using technology in class

Figure 5 below shows the overall teacher confidence level in using technology during teaching and learning.

What is your level of confidence in using technology in science classes?

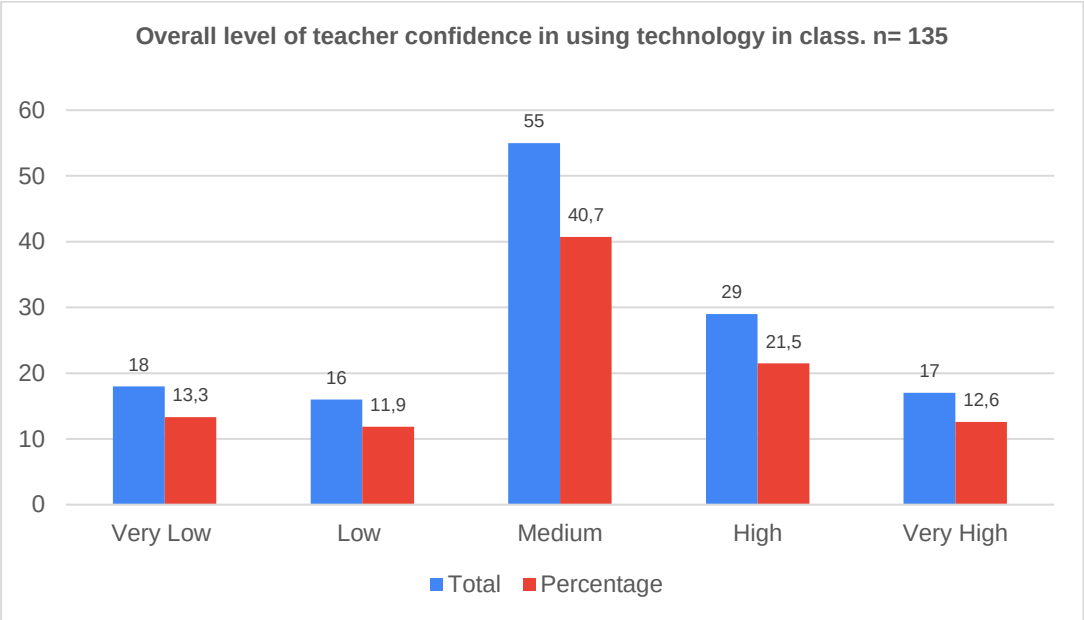


Figure 5: Overall teacher confidence level in using technology during pedagogy

Figure 6 illustrates a comparison of the level of teacher confidence in using technology in class across quintiles 1 to 5 schools.

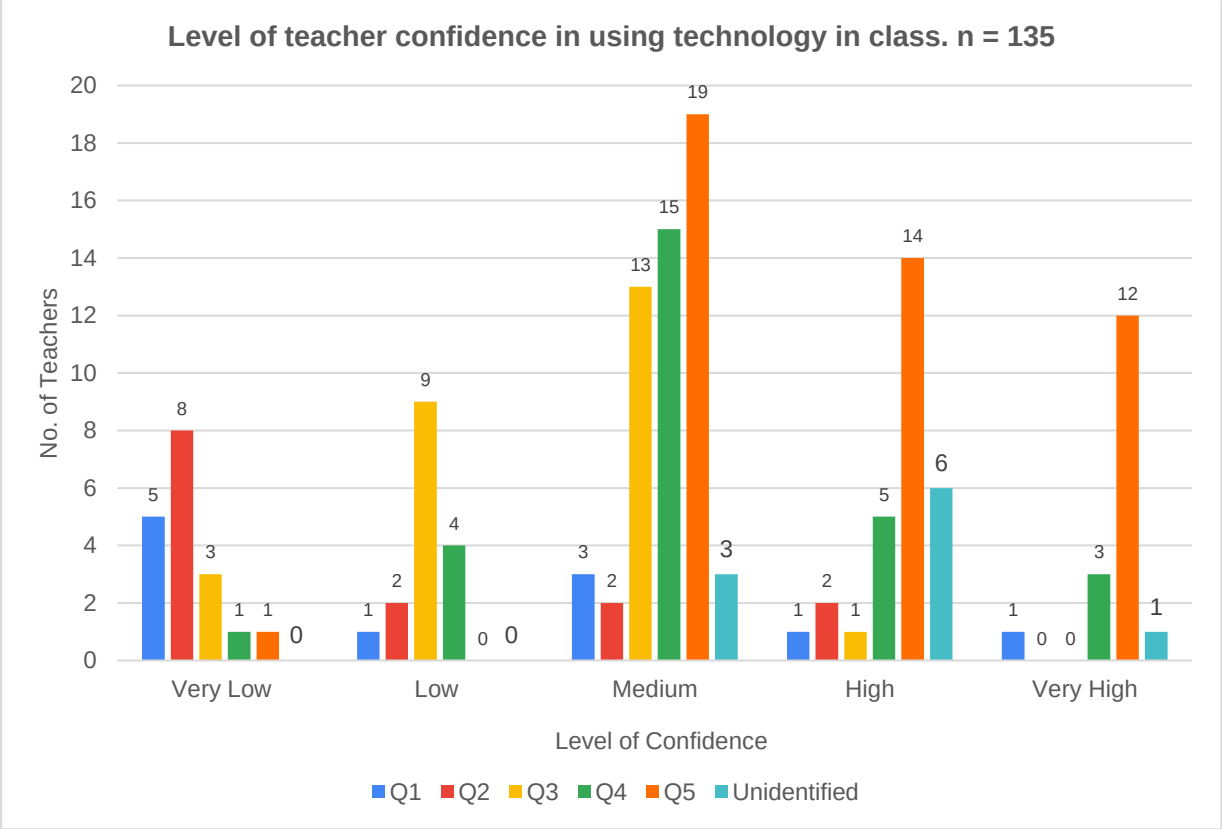


Figure 6: A comparison of the level of teacher confidence in using technology in class across quintile 1 to 5 schools

Based on Figures 5 and 6, 25.2% (34) of the teachers indicated that their confidence level is "very low" (13,3%) and (11.9%) "low", of which 82.4% are from quintiles 1-3 schools.

The majority of the teachers, 55 (40.7%), reported a "medium" confidence level across all quintiles. On the other hand, 34.1% (46) indicated a "high" (21.5%) to a "very high" (12.6%) level of confidence, of which the bulk (73.9%) are from quintiles 4 and 5). An interesting observation is the observation of two extremes in the confidence levels between the poor (Q 1- 3) and rich (Q 4 and 5) school

teachers; of the total number of respondents from quintiles 1 -3, the survey shows that 45.1% (23) science teachers reported a "medium to very high" confidence level compared to 91.9% (68) respondents from quintile 4 and 5 schools.

Figure 7 presents the distribution of teachers who have and have not heard of virtual labs.

Have you ever heard of the term virtual labs?

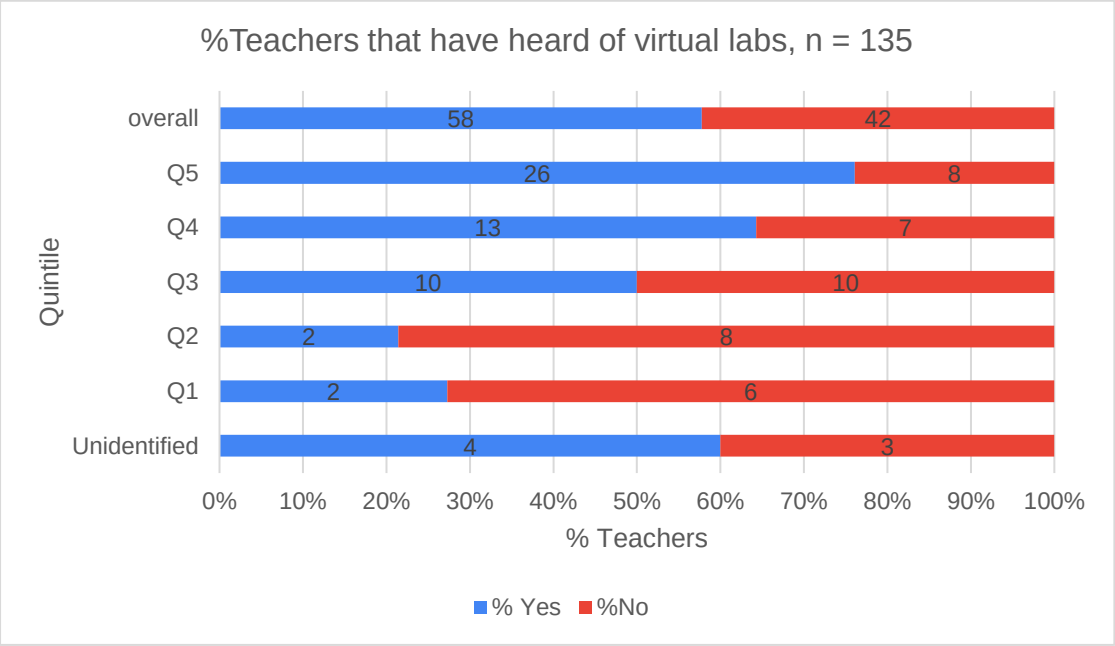


Figure 7: Percentage of teachers who have or have not yet heard of the term virtual lab.

From Figure 7, it can be seen that 57.8% (78) of the teachers indicated that they have heard of virtual labs, of which 67.9% (53) are from quintiles 4 and 5 and 24.4% (19) are from quintile 1 – 3 schools. Of the 42.2% (57) respondents that indicated they have not heard of the virtual labs, the bulk of them, 56.1% (32), are from quintile 1 – 3 schools. Of all the respondents from quintiles 1 -3 schools,

only 37.3% confirmed that they have heard of virtual labs compared to 71.6% (53) from quintiles 4 and 5.

Figure 8 below is a comparison illustration of the number of teachers who (i) know and those who do not know where to access virtual lab teaching and learning materials, (ii) have, and those who do not have access to virtual lab material, and (iii) know where to access and those who have access to virtual lab teaching and learning materials in schools.

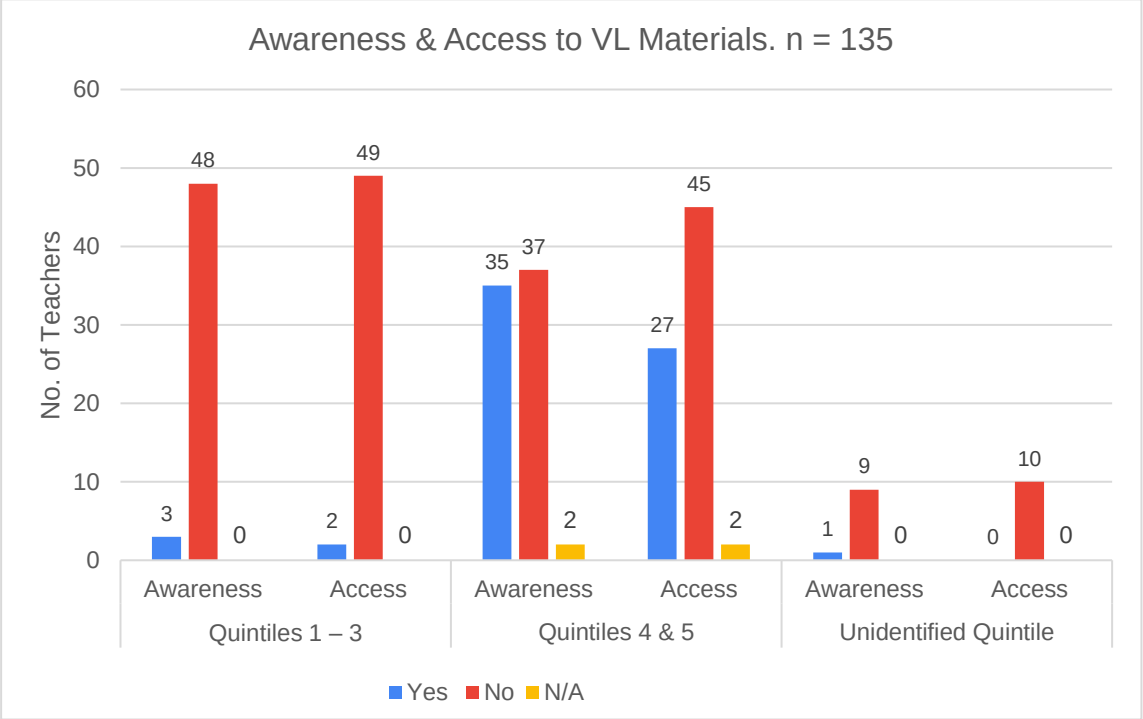


Figure 8: A comparison of the number of teachers who know where to access and those who have access to virtual lab teaching and learning materials in schools

Awareness: Do you know where you can access virtual lab teaching and learning resources/materials?
Access: Do you have access to virtual lab material?

As illustrated in Figure 8, the survey has shown that the majority, 69.6% (94) of teachers across all the quintiles, do not know where to access virtual lab teaching and learning resources/materials, of which 51.1% (48) are quintile 1 – 3 schools, and 39.4% are from quintile 4 and 5 schools. Of all the respondents from quintiles 1 – 3 schools, 94.1% (48) do not know where to access virtual lab teaching and learning resources/materials, compared to 50.0% from quintiles 4 and 5.

Regarding access, most of the teachers, 77.1% (104), do not have access to virtual lab material, of which 47.1% (49) are from quintile 1 – 3 schools, and 43.3% (45) are from quintile 4 and 5 schools.

Of all the respondents from quintiles 1 -3 schools, 96.1% (49) do not have access to virtual lab material compared to 60.8% (45) from quintiles 4 and 5 schools. Thus, most teachers across all the quintiles neither know where to access virtual lab teaching and learning resources/materials nor do they have access.

The extent of use of virtual labs (VL) in science education by the teacher

Table 6 provides the results on the frequency of the teacher use of science videos, animations, simulations, head-mounted display (HMD) immersive virtual lab during class to (a) explain science concepts, (b) demonstrate science concepts and experiments, and (c) to do experiments.

How often do these activities happen in your science class? Scale 1 = Never; 2 = Seldom; 3 = Usually; 4 = Always; 5 = N/A

Table 6: Extent of use of virtual labs (VL) in science education by the teacher during pedagogy

Question	Quintiles 1 – 3 Schools					Quintiles 4 & 5 Schools					Unidentified					Total				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
I use science videos to explain concepts	30	12	6	1	2	6	27	36	5	0	1	5	4	0	0	37	44	46	6	2
I use science videos to demonstrate experiments	28	13	6	2	2	5	14	37	18	0	1	5	3	0	1	34	32	46	20	3
I use animations to explain concepts	40	3	6	0	2	38	22	13	1	0	2	4	4	0	0	80	29	23	1	2
I use animations to demonstrate experiments	40	4	5	0	2	33	28	12	1	0	2	4	3	0	1	75	36	20	1	3
I use simulations to explain concepts	40	5	3	1	2	36	17	20	1	0	2	2	5	0	1	78	24	28	2	3
I use simulations to do experiments	42	4	2	1	2	34	13	18	9	0	2	5	3	0	0	78	22	23	10	2
I use head mounted display (HMD) immersive virtual lab to explain concepts	46	1	0	1	3	59	8	1	0	6	7	1	1	0	0	112	10	2	1	9
I use head mounted display (HMD) immersive virtual lab to do experiments	45	1	1	1	3	59	8	1	0	6	7	1	1	0	1	111	10	3	1	10

Below is the narrative of the analysis of the results presented in table 6. s

Use science videos to explain concepts and demonstrate experiments by the teacher.

As can be seen in Table 6, (a) 27.4% (37) teachers across all quintiles never used science videos to explain concepts, of which 81.1% (30) are from quintiles 1 – 3 schools, and only 16.2% (6) are from quintile 14 and 4 schools; (b) 32.6% (44) indicated that they seldomly use science videos to explain concepts; (c) 34.1% (46) reported that they usually use science videos to explain concepts, the majority 78.3% (36) being from quintile 4 and 5 schools, and a handful of teachers 4.4% (6) teachers indicated that they always use science videos to explain concepts, of which 83.3% are from quintile 4 and 5 schools.

Concerning the use of videos to demonstrate experiments, the survey results have shown that (a) 25.2% (34) of the teachers never used science videos to demonstrate experiments, of which most of them 82.4% are from quintiles 1-3 and 14.7% from quintile 4 and 5; (b) 23.7% (32) seldomly use science videos to demonstrate experiments; (c) 34.1% (46) usually use science videos to demonstrate experiments, of which the majority 80.4% are from quintiles 4 and 5 schools; and (d) only 14.8% always use science videos to demonstrate experiments, to which quintile 4 and 5 schools contributed 90.0% and only 10% from quintiles 1-3 schools.

Use science animations to explain concepts and demonstrate experiments by the teacher.

As presented in Table 6, (a) most of the teachers, 59.3% (80) across all the quintiles, never used animations to explain science concepts, to which 47.5% and 50.0% are from quintiles 4-5 and 1 -3 schools respectively; (b) 21.5 (29) seldomly use animations to explain concepts, to which 75.8% are from quintile 4 and 5, and 10.3% from quintiles 1 – 3 schools, (c) 17.0% (23) usually use animations to explain concepts, of which only 26.1% are from quintiles 1 -3 schools and 59.1% quintiles 4 and 5 schools, (d) only 1 (0.7%) teacher form quintile 5 school indicated that he/she always use animations to explain concepts.

Focusing on the use of animations by teachers during class to demonstrate experiments, the survey results indicate that (a) the majority, 55.6% (75) of the teachers across all quintiles never used animations to demonstrate experiments, 53.3% being from the quintiles 1-3 schools and 48.0% from quintiles 4 and 5 schools; (b) 26.7% (36) of the teachers seldomly use animations to demonstrate experiments, of which 77.8% are from quintiles 4 and 5 and 11.1% from quintiles 1 -3 schools; (c) 14.8% (20) of the teachers usually use animations to demonstrate experiments, of which 60.0% (12) are from quintiles 4 and 5 schools, and 25.0% are from quintiles 1 - 3 schools; and (d) only 1 (0.7%) teacher form quintile 5 school reported that he/she always use animations to demonstrate experiments.

Use science simulations to explain concepts and perform experiments by the teacher.

As depicted in Table 6, (a) the majority, 57.8% of the teachers reported that they never used simulations to explain concepts, of which the bulk 51.3% (40) is from quintiles 1 – 3 schools and 46.2% (36) are from quintiles 4 and 5 schools; (b) 17.8% (24) of the teachers seldomly use simulations to explain concepts, of which 70.8% and 20.8% are from quintile 4 - 5 and 1 -3 schools respectively; (c) 20.7% (28) usually use simulations to explain concepts, of which 71.4% are from quintiles 4 and 5 and 17.9%, quintiles 1- 3 schools; and (d) only 1.5% (2) always use simulations to explain concepts.

Considering the use of simulations by teachers in class, the survey results indicate that (a) most of the teachers, 57.8%, never used simulations to do experiments, of which 53.8% are from quintiles 1 -3 and 43.6% are from quintiles 4 and 5 schools, (b) 16.3% seldomly use simulations to do experiments, of which 59.1% are from quintile 4 and 5 and 18.2% from quintile 1 -3 schools; (c) 17.0% usually use simulations to do experiments, of which 78.3% are from quintiles 4, and 5 and 8.7% are from quintiles 1 – 3 schools; and only 7.4% always use simulations to do experiments, 9 (90.0%) from quintiles 4 and 5 and only 1 (10%) teacher form quintiles 1- 3 schools.

Use a head-mounted display (HMD) immersive virtual lab to explain concepts and perform experiments by the teacher.

Across all the quintiles, the survey indicated that (a) the greater proportion of the teachers, 83.0% (112), never used a head-mounted display (HMD) immersive virtual lab to explain concepts nor do experiments; (b) 7.4% (10) of the teachers seldomly use the HMD immersive virtual lab to explain concepts or do experiments; (c) 1.5% (1) and 2.2% (3) usually use HMD immersive virtual lab to explain concepts and to do experiments respectively, and (d) only 1 (0.7%) teacher always use HMD immersive virtual lab to explain concepts and do experiments.

The following section presents the survey outcomes on learner access to digital devices and the extent to which learners are engaged and actively participate in digital learning using virtual labs in class.

The extent of learner engagement in digital learning through virtual labs

Figure 9 is a graphical representation of the number of schools in which (i) each learner has a digital device (DD per learner), (ii) the class has digital devices that learners can share (Class has DD), and (iii) the school has digital devices that the class can use sometimes (School has DD).

What access do the learners in your science class have to digital devices (computers, tablets, smart phones) during class?

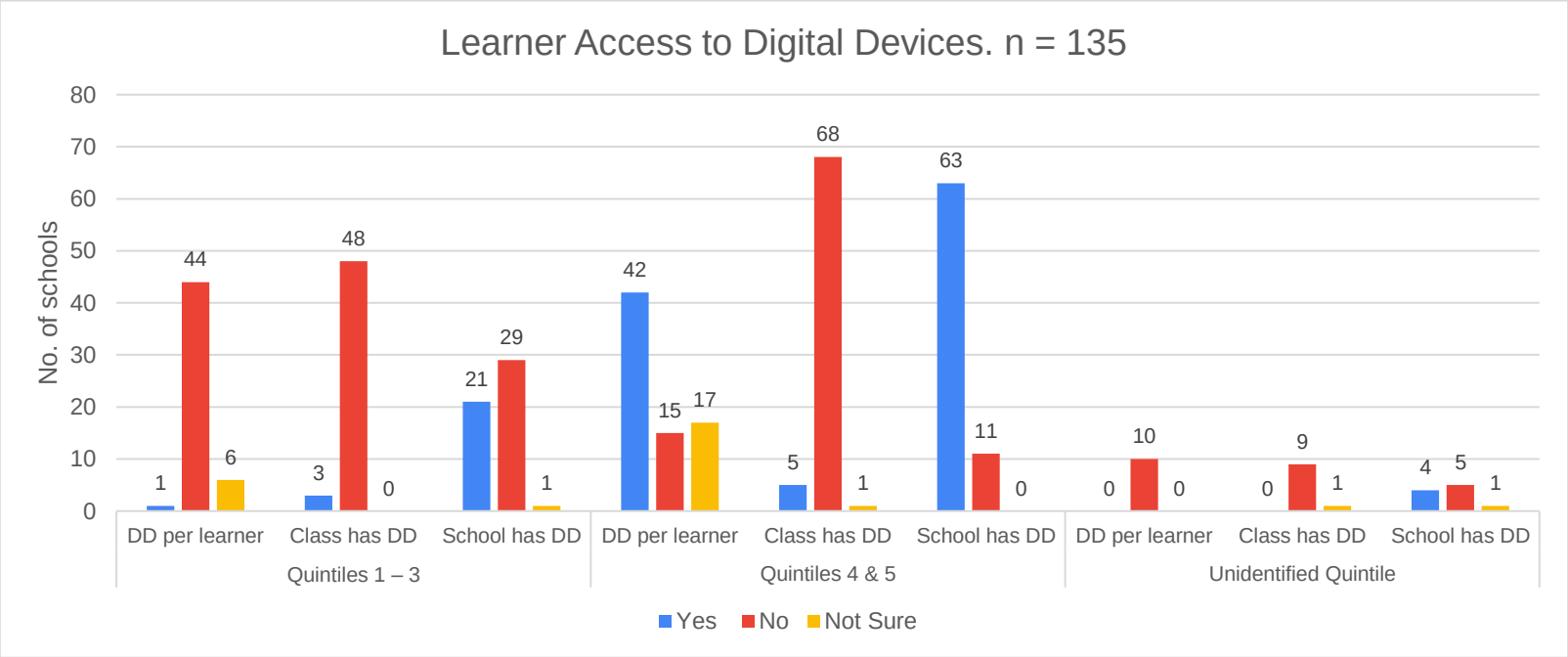


Figure 9: A comparison of the number of schools in which learners have access to digital devices to support learning during class

Given below is the narrative of the analysis on the availability of digital devices to learners in schools to support learning during class based on Figure 9.

The survey results have shown that in 43.7% (59) of the schools, learners do not have their own digital devices to support learning; 74.5% (44) are from quintile 1-3 schools, and 25.4% are from quintile 4 and 5. Comparing the number of schools where learners have their own devices, in quantile 4 and 5 schools, 56.7% (42) and only 1 (1.9%) quintile 1-3 school indicated that learners have their devices to support learning.

The overwhelming majority of the schools, 85.9% (116), of the school across all quintiles do not have digital devices that students can share. Both paying (Q 4 & 5), and no-fee schools (Q 1- 3) registered very high numbers 91.2% (68) and 94.1% (48) respectively.

Overall, 62.2% (84) schools reported that they do have digital devices that the class can use sometimes, 75.0% (63) are from quintiles 4 and 5 schools, and 26.2% (22) are from quintile 1-3 schools. Comparing quintiles 4 and 5 and quintiles 1 -3, most schools in quintiles 4 and 5, 85.1% (63) have digital devices that the class can sometimes use for learning compared to 41.2% (21) in quintiles 1- 3 schools.

Table 7 provides a summary of the frequency of teachers engaging learners' use of science videos, animations, simulations, HMD immersive virtual lab during class to (i) understand science concepts and experiments better, (ii) do experiments, and (iii) to collaborate with their peers.

How often do you and your learners do the following activities on digital devices (computers, laptops, tablets, or smartphones) during science lessons? Scale: 1 = Never, 2 = Seldom, 3 = Usually, 4 = Always, 5 = Not Sure

Table 7: Extent of learner engagement in digital learning through virtual labs

Question	Quintiles 1 - 3 Schools					Quintiles 4 & 5 Schools					Unidentified					Total				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Learners engage with science videos to understand science concepts better	38	9	3	1	0	11	31	26	6	0	4	2	3	0	1	**53**	**42**	**32**	**7**	**1**
Learners engage with science videos to understand science experiments better	37	10	3	1	0	9	24	32	9	0	4	3	3	0	0	**50**	**37**	**38**	**10**	**0**
Learners engage with animations to understand science concepts better	46	3	1	1	0	44	17	12	1	0	3	3	4	0	0	**93**	**23**	**17**	**2**	**0**
Learners engage with animations to understand science experiments better	45	4	1	1	0	44	18	9	3	0	3	3	4	0	0	**92**	**25**	**14**	**4**	**0**
Learners use simulations to understand science concepts better	47	1	2	1	0	40	13	18	3	0	3	4	3	0	0	**90**	**18**	**23**	**4**	**0**
Learners use simulations to do science experiments	47	2	1	1	0	40	11	14	9	0	4	3	1	1	0	**91**	**16**	**16**	**11**	**0**
Learners use head mounted display (HMD) immersive virtual lab to interact with science concepts	47	2	1	0	1	62	6	1	0	5	7	3	0	0	0	**116**	**11**	**2**	**0**	**6**
Learners use head mounted display (HMD) immersive virtual lab to do science experiments	47	2	1	0	1	62	6	1	0	5	7	3	0	0	0	**116**	**11**	**2**	**0**	**6**
Collaboration: Learners work in groups using simulations to explore science concepts and do experiments using a single/one device	46	2	3	0	0	38	18	18	0	0	6	4	0	0	0	**90**	**24**	**21**	**0**	**0**
Collaboration: Learners work in groups remotely/online using simulations to explore science concepts and experiments each using his/her own devices	45	2	2	0	4	39	18	7	0	10	7	3	0	0	0	**91**	**23**	**9**	**0**	**14**

The data from the survey reflect a strong positive correlation between learners' extent of engagement in digital learning through virtual labs during class and the extent of use of virtual labs by teachers in class across all the ten measurement parameters. Therefore, the analysis given in the section below is based on the survey results illustrated in Table 7.

Learners engage with science videos to understand science concepts and experiments better.

As can be seen from Table 7, 39.2% (53) and 37.0% (50) of schools have learners that never engaged with science videos to understand science concepts and experiments better, respectively, of which the majority, 71.6% (38) and 74.0% (37) respectively are all from quintile 1-3 schools. Only 31.1% (42) and 27.4% (37) of the schools have learners that seldomly engage with science videos to understand science concepts and experiments better, respectively, of which the bulk 73.8(31) and 64.9% (24) are from quintile 4 and 5 schools respectively. Similar results are observed for the schools that have learners who usually engage with videos to understand science concepts and experiments; 23.7% (32) and 28.1% (38), respectively, with most schools, 81.3% (26) and 84.2% being quintiles 4 and 5 respectively. It is worth mentioning that only 1 (1.9%) school from quintile 1-3 schools indicated that they have learners who usually engage with science videos to understand science concepts and experiments better. Regrettably, very few schools, only 5.2% (7) and 7.4% (10), have learners who always engage with science videos to understand science concepts and

experiments better respectively, still with the majority 85.7(6) and 90.0% (10) being quintiles 4 and 5 schools respectively.

Learners engage with animations to understand science concepts and experiments better.

The survey has shown that the majority of schools, 68.9% (93 and 68.1% (92) and 37.0% (50) of schools have learners that never engaged with animations to understand science concepts and experiments better, respectively. Separately, both quintiles 4 and 5 and quintiles 1-3 schools reported that most of their schools, 59.5% (44) and 92.2% (46), have learners who never engaged with animations to understand science concepts and experiments better, respectively. Considering the schools that have learners that seldomly engage with animations to understand science concepts and experiments better, the results show 17.0% (23) and 18.5% (25), respectively, with the majority 73.9% (17) and 72.0% (18) being quintile 4 and 5 schools respectively. The results show a decrease in the number of schools that have learners that usually engage with animations to understand science concepts and experiments better; 12.3% (17) and 10.4% (14), respectively, still having the bulk of the schools, 70.6% (12) and 64.3% (9) belonging to quintile 4 and 5 schools respectively. Again, only one school, 1 (1.9%) from quintiles 1 -3, indicated that they have learners who usually engage with science animations to understand science concepts and experiments better also reported that its learners usually engage with animations to understand science concepts and experiments better.

Learners use simulations to understand science concepts better and to do experiments.

A similar trend observed in the above-mentioned categories is also seen in schools with learners who use simulations to understand science concepts better and do experiments. Thus, the greater proportion of schools, 66.7% (90) and 67.4% (91), have learners that never used simulations to understand science concepts better and to do experiments, respectively, both quintiles 1 -3 and 4 – 5 schools recorded high numbers, 92.2% (47) and 54.0% (40) correspondingly. On the other hand, fewer schools, 13.3 (18) and 11.9% (16), have learners that seldomly use simulations to understand science concepts better and to do experiments, respectively, of which the majority, 72.2% (13) and 68.8% (11) are from quintile 4 and 5. Whilst only 17.0% (23) and 11.9% (16) of the schools reported that they have learners who usually use simulations to understand science concepts better and do experiments. A handful of schools, 2 (3.9%) and 1 (1.9%) for quintiles 1- 3; and 18 (24.3%) and 14 (10.4%) for quintiles 4 and 5 have learners that usually use simulations to understand science concepts better and to do experiments respectively. Of the schools that indicated that they have access to the internet and digital resources for learning, very few, 3.0% (4) and 8.1% (11), have learners who 'always' use simulations to understand science concepts better and do experiments. Of these schools, only 1 (1.9%) belong to 1-3, while 3 (4.1%) and 9 (12.2%) are from quintiles 4 and 5, respectively.

Learners use a head-mounted display (HMD) immersive virtual lab to interact with science concepts and do experiments.

Across all the quintiles, the survey unveiled that (a) the vast majority, 85.3% (116) of the school have learners that never used HMD immersive virtual lab to interact with science concepts and do experiments, (b) 8.1% (11) seldomly use HMD immersive virtual lab to interact with science concepts and do experiments, (c) 1.5% (2) usually use HMD immersive virtual to interact with science concepts and do experiments, and (d) none of the schools reported that learners at their school always use HMD immersive virtual lab to interact with science concepts and do experiments.

Collaboration: Learners work in groups using simulations to explore science concepts and do experiments

Looking at the number of schools that have learners that work in groups using simulations to explore science concepts and do experiments, the general pattern of the results are comparable to the ones observed in the categories mentioned above, with (a) most schools, 66.7% (90) and 67.4% (91) having learners that never collaborated, in-class nor remotely using simulations to explore science concepts and do experiments respectively; (b) relatively few schools, 17.8% (24) and 17.0% (23) having learners that seldomly collaborate, in class and remotely using simulations to explore science concepts and do experiments respectively; (c) a handful of schools, 15.6% (21) and 6.7% (9) having learners that usually collaborate, in class and remotely using simulations to explore science concepts

and do experiments respectively; and (d) none of the schools have learners who always collaborate, in class and remotely using simulations to explore science concepts and do experiments respectively.

The next section presents the results of the study under the third research question, which sought to establish the value that teachers have experienced and observed ever since they started integrating virtual labs into the teaching and learning of science subjects.

4.4 Results pertaining to proposition 3

Proposition 3: *The use of virtual labs in science pedagogy improves learning outcomes, among other, learner achievements.*

This section is divided into two sub-sections as follows:

- use of virtual labs for teaching and learning in science classes and
- the value derived from using virtual labs in science education.

Figure 10 represents the number of schools that use virtual labs (web-based simulations, e.g., PHeT Interactive Simulations and Labster) to support science education during pedagogy. As illustrated in Figure 10, the majority of the schools, 75.6% (102), indicated that they do not use virtual labs for teaching and learning in their science classes, of which the quintile 1 -3 contributed 48.0% (49) and quintile 4 and 5 44.1% (45) schools. In comparison, 96.1% (49) of all the quintile 1-3 schools do not use virtual labs for teaching and learning in their science classes relative to 60.8% of the quintile 4 and 5 schools.

Do you use virtual labs (web-based simulations e.g., PHeT Interactive Simulations, Labster, etc.) for teaching and learning in your science class(es)?

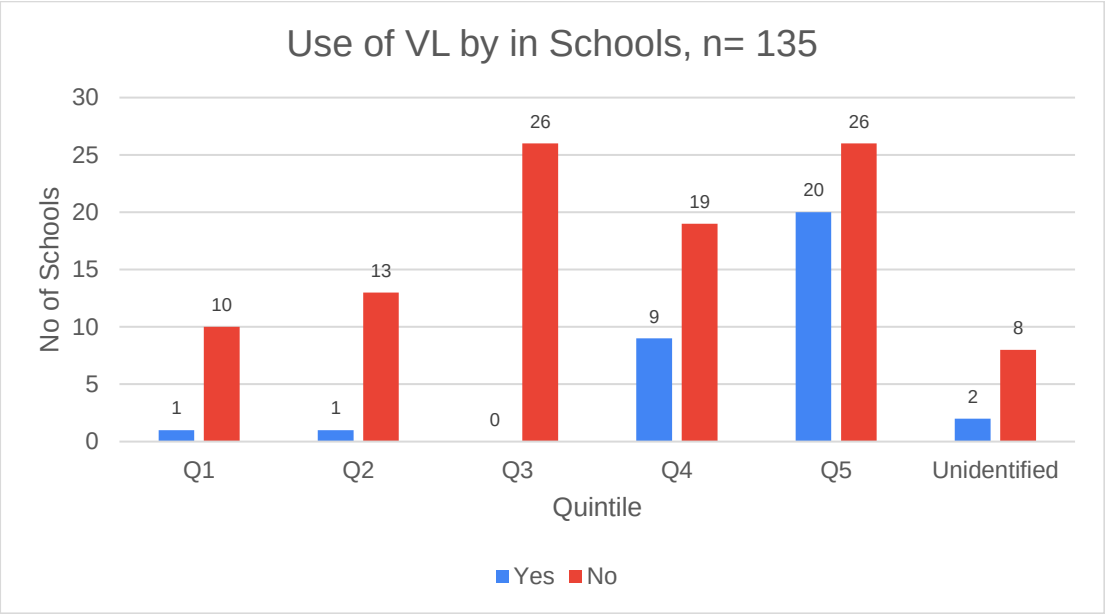


Figure 10: Use of virtual labs for teaching and learning in science classes across quintiles

Figure 11 presents teachers' rating of the level of the value that they have experienced and observed ever since they and their learners started using virtual labs for teaching and learning. It should be noted that Figure 11 only considered teachers that confirmed the use of virtual labs (web-based simulations e.g., PHeT Interactive Simulations and Labster) during pedagogy; thus, n = 33. It is also worth noting that nine of the respondents did not follow the proper instruction on the last question, which required them to tick N/A if they were not using virtual labs; hence their responses were not considered in the analysis of this question.

Consider the following statement: ‘Ever since my leaners and I started using virtual lab for teaching and learning, I have observed the following:

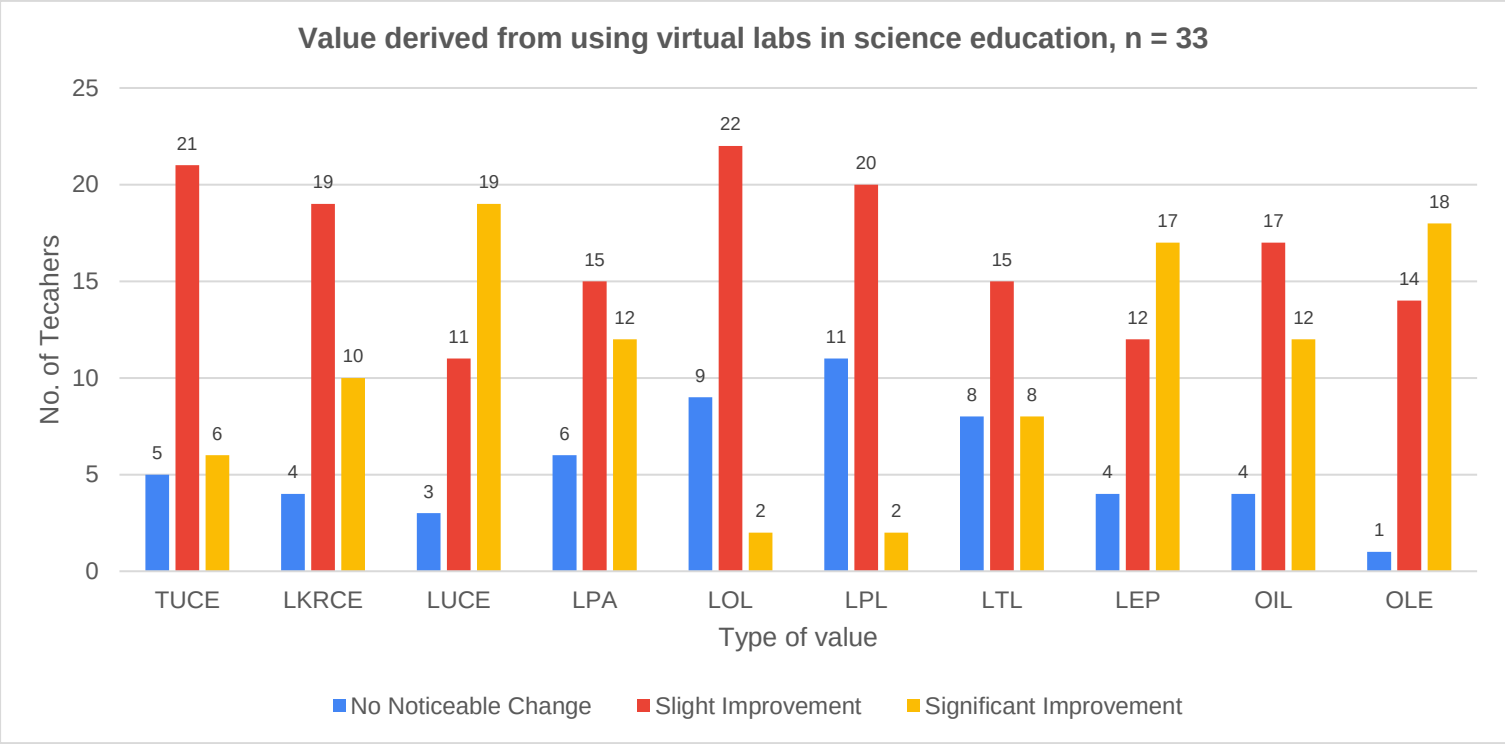


Figure 11: Teachers’ rating of the level of the value that they have experienced and observed ever since they and their leaners started using virtual lab for teaching and learning

Acronym	Description
TUCE	Level of teacher's understanding of science concepts and experiments
LKRCE	Level of learner knowledge retention of science concepts and experiments
LUCE	Level of learner's understanding of science concepts and experiments
LPA	Level of learner performance and achievement in the subject
LOL	Level of learner ownership of their own learning
LPL	Level of learner personalised learning
LTL	Level of collaboration and teamwork among learners
LEP	Level of learner engagement and participation during classes
OIL	Level of the overall interest of learners in science subject
OLE	Level of the overall teaching and learning experience

The analysis given in the section below is based on the survey results illustrated in Figure 11.

Level of teacher's understanding of science concepts and experiments (TUCE)

As a point of reference, Figure 11 provides a summary of the value derived from using virtual labs in science education based on the teacher's experience and observation ever since he/she started integrating virtual labs into science education. Of the overall 33 (26.2%) of the teachers who use virtual labs for teaching and learning, (a) 5 (15.2%) reported that ever since they started using the virtual lab for teaching and learning, there was no noticeable change in their level of understanding of science concepts and experiments; (b) while 21 (63.6%) reported a slight improvement, and (c) 6 (18.2%) a significant improvement.

Level of learner knowledge retention of science concepts and experiments (LKRCE)

Regarding the level of learner knowledge retention of science concepts and experiments, ever since the teacher started using virtual labs for teaching and learning, only 4 (12.1%) of the teachers reported that they did not notice any change. In comparison, 19 (57.6%) indicated that they witnessed a slight improvement and 10 (30.3%) reported that they have observed a significant improvement.

Level of learner's understanding of science concepts and experiments (LUCE)

With reference to Figure 11, focusing on the changes in learner level of understanding of science concepts and experiments ever since the teacher started using virtual labs for teaching and learning, just 3 (9.1%) teachers reported that there was no noticeable change, relatively more teachers, 11 (33.3%) reported a slight improvement. More than half of the teachers, 19 (57.6%), observed significant improvement.

Level of learner performance and achievement in the subject (LPA)

Considering the changes in the learner level of performance and achievement in the subject ever since the teacher started implementing virtual labs during pedagogy, a small number of teachers, 6 (18.2%) that did not notice much change, almost half of the teachers, 15 (45.5%) reported that they observed a slight improvement in their learners. In comparison, 12 (36.4%) of the teachers

attested to a significant improvement in their learner level of performance and achievement in the subject.

Level of learner ownership of their learning (LOL)

Looking at the changes observed in the learner level of ownership of their learning following the use of virtual labs in class as teaching and learning tools, the study results show that 9 (27.3%) teachers did not observe any changes, while more than half of teachers, 22 (66.7%) indicated that they witnessed a slight improvement. Only 2 (6.1%) teachers reported having observed a significant improvement in their learner's level of ownership of their learning.

Level of learner personalised learning (LPL)

The findings from the survey indicate that, of the overall 33 (26.2%) of the teachers who use virtual labs for teaching and learning, 11 (33.3%) did not notice much change with respect to any changes in learner level of personalised learning, while most teachers 20 (60.6%) attested that there was a slight improvement in learner level of personalised learning and only 2 (6.1%) teachers witnessed a significant improvement in the level of learner personalised learning.

Level of collaboration and teamwork among learners (LTL)

Based on Figure 11, the results of the survey revealed that 8 (24.4%) teachers reported that ever since they started using the virtual lab for teaching and learning, there was no noticeable change in the level of collaboration and teamwork among their learners. In contrast, nearly half of the teachers, 15

(45.5%), did observe a slight improvement, and a handful, [8 (24.2%)] of the teachers reported that they observed a significant improvement in the level of collaboration and teamwork among their learners.

Level of learner engagement and participation during classes (LEP)

With reference to the changes observed in the learner level of engagement and participation during classes ever since the teacher started using the virtual lab for teaching and learning, 4 (12,1%) reported that they noticed no change, 12 (36.4%) teachers reported that they observed a slight improvement. In comparison, slightly above half of the teachers, 17 (51.5%), witnessed a significant improvement.

Level of the overall interest of learners in science subjects (OIL)

Regarding the changes in the level of the overall interest of learners in science subjects, of the total 33 (26.2%) teachers who use virtual labs for teaching and learning, very few, 4 (12.1%) reported not to have observed any noticeable change, while slightly above half of the sample, 17 (51.5%) attested to a slight improvement and 12 (36.4%) reported a significant improvement.

Level of the overall teaching and learning experience (OLE)

As illustrated in Figure 11, close to half of the teachers, 14 (42.4%), reported that ever since they started integrating virtual lab into science pedagogy, they observed a slight improvement in the level of overall teaching and learning experience, while just 1 (3.0%) teacher reported not to have observed any

noticeable change, while most of the teachers, 18 (54.5%) reported that they witnessed a significant improvement in their learner level of overall teaching and learning experience.

CHAPTER 5. DISCUSSION OF THE RESULTS

5.1 Introduction

Following the presentation and narration of the results in chapter four, this section endeavours to answer the “so what” question by (i) interpreting the results in relation to the context, (ii) bringing out the meaning and significance of the results by mapping them back to the research questions, (iii) comparison of the study findings with related studies (especially the ones done in same or similar context); identifying and explaining any gaps, positive correlation and anomalies from the existing body of literature.

This section is divided into four sub-sections as follows:

- demographics and response rates
- discussion pertaining to proposition 1
- discussion pertaining to proposition 2
- discussion pertaining to proposition 3
- chapter overall discussion.

The chapter’s overall discussion section presents an overall discussion of the study results based on the three propositions made. It consolidates and summarises the findings from the three propositions, outlining how they link or relate. It also highlights trends or patterns observed among the constructs across the three propositions relating to no-fee schools (quintiles 1-3) and fee-paying schools (quintiles 4 and 5).

5.2 Demographics and response rates

In this study, opinions from the science teachers on the integration of virtual labs into science education were analysed using descriptive statistics. Statistical software for quantitative data analysis, SPSS 25, was partly used to analyse the results. The results from all the statistical analyses are presented in the sections that follow:

In total, 135 teachers responded, giving a 65.2% response rate. Of the 135 respondents, all were teaching science subjects at the time of the survey, of which 120 (88.9%) indicated that they were science teachers by specialisation and the remaining 17 (12.6%) were non-science specialists. The survey was sent to one teacher per school; hence the number of respondents indicates the number of schools that participated. Figure 12 summarises the number of respondents per quintile.

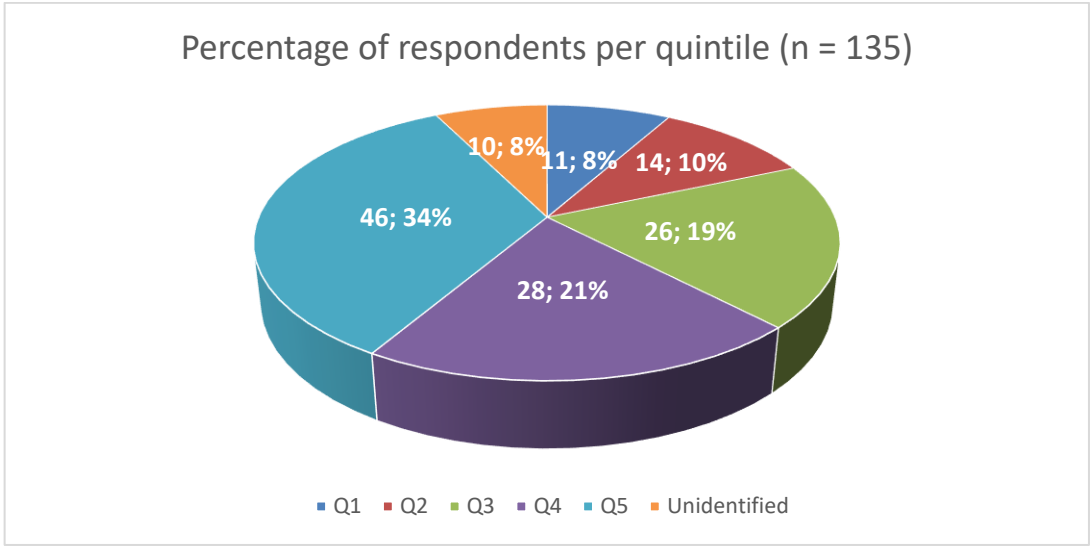


Figure 12: Percentage of respondents per quintile to which the school belongs.

Results displayed in figure 12 indicate that quintile 5 schools had the highest number of responses, 46 (34%), with quintile 1 schools recording the lowest number of responses. Ten respondents indicated that they did not know which quintile category their schools belonged to. There is a gradual decrease in the number of responses from the affluent, well-resourced schools in quintile 5 progressing down to the under-resourced schools, in quintile 1. The observed trend could be attributed to the availability or unavailability of digital resources and internet accessibility in schools. Furthermore, some teachers may prefer not to use their own devices or data to respond to the survey questionnaire, adding to the low response rates from the poorer schools (quintiles 1 and 2) due to unavailability of digital resources and inaccessibility of internet connectivity. It could be argued that the trend followed the distribution pattern of the number of schools per strata (quintile) based on the proportionate stratified random sampling method used. Quintile 5 schools contribute the highest proportion of the total number of schools, 640 (30.9%) in Gauteng, followed by quintile 4 schools with 478 (23.15), quintile 3 has 418 (20.2%), with quintiles 1 and 2 having 274 (13.2%) and 259 (12.5%).

Analysis of the survey results on the number of respondents per type of school revealed that he majority of respondents were from primary schools, 67 (49.6%), while 60 (44.4%) were from secondary schools, and intermediate and combined schools registered a total of 4 (3.0%) respondents.

The following section is a discussion of the results under the first proposition.

5.3 Discussion pertaining to proposition 1

Proposition 1: *The constraints faced in the current methodologies used in science education are contributing to poor learner performance in science in South African public schools.*

As revealed in Table 3, the findings show that most of the schools (77.8%) have internet connectivity, which aligns with the Department of Basic Education's National Education Infrastructure Management System (NEIMS, 2021) data. The NEIMS data shows that 1 327 (63.9%) of the schools in Gauteng have internet connectivity for teaching and learning and that 1 441 (69.5%) have internet for administrative purposes. There is a general pattern emerging, as illustrated in Table 3, in which most of the well-resourced schools (Q 4 and 5) have access to the internet; have stable and reliable internet; have internet speed that can support teaching and learning. This is not the case in the under-resourced schools (Q 1-3).

There is a general alignment of the objectives of this study with those of the Department of Basic Education. For instance, raising awareness in the system and promoting the use of virtual labs to improve learning outcomes and experience in science subjects. According to Mwapwele et al. (2019), the use of Information Communication Technologies (ICTs), internet, computers, tablets, smartphones included, have been adopted in South African Schools with the national objectives of ensuring that quality education is delivered in schools through increased access to and sharing of teaching and learning materials. This concept is supported by empirical evidence from studies by Gialamas et al.

(2013), in which they "investigated student teachers' perceptions about the impact of internet usage on their learning and future jobs". Their findings indicated that internet-based digital technologies improve learning outcomes and experience by making learning more interesting and fun, broadening the scope of understanding, in so doing providing a conducive environment for meaningful learning. Furthermore, the longer the teachers engage with digital technology, the more conversant and comfortable they become, and they are more likely to infuse it during teaching and learning (Gialamas et al., 2013). Hence the need to expose both teachers and learners to ICT-based learning to achieve the national objectives.

Regarding the number of learners that possess digital resources, the findings of this study show a relatively small percentage, 20.7% (28) of learners have personal digital devices (tablets, smartphones, and laptops). The small percentage can be attributed to the fact that most schools in South Africa do not allow the use of personal digital devices during school hours. This observation is supported by a study done in South African schools by Mwapwele et al. (2019), which indicated that 83% (163) of the teachers who took part in the study reported that their schools forbid the “use of personal digital devices” by learners during schooling hours. Based on the research findings, it is clear that the banning of the use of personal digital devices by learners is more rampant in no-fee schools, in which only 7.1% (2) compared to 92.9% (26) (in fee-paying schools) of the schools indicated that learners have their devices used for digital learning. However, research (Akçayir et al., 2016; Chen & Tsai, 2020; Liu et al., 2021;

Mwapwele et al., 2019; Padayachee, 2017) has shown that mobile phones can be effectively used for digital learning without the restriction of time and location; learners can still utilise them for learning when they are home. Availability of digital resources (e.g., smartphones) and internet connectivity to the learner at all times (24/7) can be exploited and encouraged to facilitate a blended learning approach, especially for the higher Grades in schools.

Considering teacher access to digital devices, the study indicates that of the schools that reported not having computers/laptops for teacher use during teaching and learning, the majority, 82.1% are from poor schools (Q1 -3), whereas of the schools that provide the teacher with digital devices, the bulk 71.9% are from affluent schools (Q4 and 5). The same trend is observed regarding teacher access to projectors, where the schools that reported having projectors for use during pedagogy, the greater proportion, 76.2%, is from quintile 4 and 5 schools with only 12.7% contribution from quintile 1 - 3 schools. These findings are supported by several studies (HSRC, 2019; TIMSS, 2020; van Dyk & White, 2019), which indicated that affluent schools (Q 4 and 5) are much better resourced than poorer schools (Q1- 3). Because of this, poorer schools have lower quality processes in teaching and learning and in the standard of curriculum delivery which leads to compromised learning outcomes in poor schools (Q 1- 3).

In a similar study by Ogbonnaya and Awuah (2019), in which learners from rich schools (Q4) outperformed learners from poor schools (Q 1- 3); the authors attributed the difference in learners' performance to the fact that rich schools (Q4) can "acquire additional teaching and learning resources to aid teaching and

enhance students' learning". Tragically, according to the DBE statistics (2017), roughly 86% of all South African public schools fall under quintiles 1 – 3 schools, catering for approximately 79% of all learners nationally.

With regards to the availability of laboratories at schools, there is a slight misalignment in the findings of this study compared to the Department of Basic Education's National Education Infrastructure Management System (NEIMS, 2021) data, which reported that only 33.5% (694) of Gauteng schools have laboratories. Instead, this study showed that slightly above half, 54.8% (74) of the surveyed schools have laboratories, either physical buildings or mobile labs. The discrepancy may have arisen from the fact that in this study, laboratories were not limited to physical buildings but instead included mobile labs. Nevertheless, the findings on the availability of labs in schools follow the same pattern as one on the availability of digital resources, with most of the wealthy schools (79.7%) having laboratories compared to poor schools (10.8%).

A similar trend to the aforementioned findings is observed concerning the availability of apparatus and chemicals for science experiments in school. The study finds out that although some schools may have labs, they never had (11.9%) apparatus and also seldomly (31.9%) have chemicals for science experiments, most of which (93.8% and 71.9% respectively) are poor schools (Q 1-3). Contrary to the observation made in poor schools, rich schools (Q 4 and 5) reported a considerably higher percentage of schools that usually (74.5%) and always (70.6%) have chemicals for science experiments. The results of this study on the availability of scientific resources in schools concur with Furiwai and Pillay

(2020)'s findings. The two studies share the same context- both were done in South African schools. Furiwai and Pillay (2020) did a research study on "the views and experiences of Grade 10 Life Sciences teachers on the compulsory practical examination" and came to the same findings as in this study that most schools do not have functional scientific infrastructures to engage learners on experiments and practical work. As observed in this study, the authors singled out the lack of basic laboratory equipment and chemicals as the major factors impeding teachers from conducting experiments and practical work. Similarly, in their research, George and Kolobe (2014) observed that of the schools that reported having laboratories, the majority (70%) were not doing chemistry experiments due to lack of and non – replenishment of chemicals and basic lab equipment and consumables.

Generally, the findings of this study show an uneven distribution of the laboratory facilities between rich (Q4 and 5) and poor (Q 1- 3) schools, and the availability of apparatus and chemicals in these schools are in agreement with the findings of several other studies (HSRC, 2019; TIMSS, 2020; van Dyk & White, 2019) that indicated that poor schools are massively under-resourced relative to wealthy schools.

Research has shown that extent of learner academic performance and achievement is significantly dependent on the availability of teaching and learning resources, among other factors (HRSC, 2019; Letsoalo et al., 2019; Pournara, 2020; TIMSS, 2020). In support of this fact, Banet et al. (2019) pointed out that European secondary schools are not optimally benefiting from the value derived

from emerging technologies in education due to a lack of the appropriate teaching and learning resources, while Klentien and Wannasawade (2016) attributed poor learner performance in science subjects to several factors including among other, lack of scientific infrastructure in schools. Within the South African context, Pournara (2020) did a comparative study of Grade 9 learners in mathematics concepts (algebra) from under-resourced schools (Q 1 – 3) and well-resourced schools (Q5 schools). The results have shown that the learners from well-resourced schools outperformed those from under-resourced schools. The HRSC (2019) and TIMSS (2020) studies indicated the same pattern, with learners from well-resourced schools achieving higher scores than learners from under-resourced schools. Thus, most poor schools teach science subjects using an abstract approach rather than an inquiry-based approach, hence poor learner performance (HSRC, 2019; Pournara, 2020; TIMSS, 2020) in these schools relative to affluent schools. Therefore, the socioeconomic status of the community in which the school is located remains one of the factors that account for the variation in learner performance across quintiles (Letsoalo, 2017).

The main purpose of experiments and practical work in science is to foster in learners science process skills such as investigation, synthesis, analysis, designing; critical thinking; creativity, problem-solving skills; communication and collaboration; enhances learner knowledge and understanding of concepts and their practical application; development of inductive and deductive reasoning (Philippe et al., 2020; Stott, 2019). However, without essential laboratory equipment and chemicals, which is the prevailing situation in most South African

schools, 80.07% (NEIMS, 2021), as supported by the aforementioned empirical evidence, schools cannot carry out experiments and practical work in science subjects. Considering the negative impact of lack of experiments and practical work in science on learning outcomes, the fact that the majority of schools 80.07%, catering for most of the learners (79%) in South Africa do not have lab facilities means there is a massive gap in the learner knowledge and understanding of science concepts among other scientific attributes. Therefore, it can be argued that the lack of scientific infrastructure in schools is one of the major causes of low learner achievements in science subjects in South Africa.

In summary, by contrast, the findings of the survey on the availability of the necessary scientific and digital resources to support science education at schools show a general pattern in which most of the rich schools (Q 4 and 5) have necessary scientific and digital resources to support science education compared to poor schools (quintile 1-3). Therefore, the unavailability and inaccessibility of digital and scientific infrastructures and resources in schools are among the major constraints faced in science education (Banet et al., 2019; HSRC, 2019; Klentien & Wannasawade, 2016; NEIMS, 2021; Penn & Ramnarain, 2019) and are contributing factors to poor learner performance in science subjects in South African public schools (HSRC, 2019; TIMSS, 2020). The big question is, with the emergence of virtual labs, an alternative to physical scientific infrastructure, is the South African schooling system ready to leverage such digital technologies for better and improved learning?

Therefore, this study's findings agree with the proposition that the constraints faced in the current methodologies used in science education are contributing to poor learner performance in science in South African public schools.

The following section is a discussion of the results under the second proposition.

5.4 Discussion pertaining to proposition 2

Proposition 2: *Teachers are not aware of the availability and value that can be derived from virtual labs and hence are not using this technology in science education.*

The results of this study on the extent of science teacher awareness of and use of virtual labs in supporting science education reveal that most teachers across all quintiles are neither aware of nor are using virtual labs during pedagogy. As mentioned in the literature review section of this report, visuals which include experiments, videos, and simulations, aid in improving the learner learning experience, which includes, among other benefits, improved leaner understanding of abstract science concepts. The finding that most teachers are not aware of and are not using virtual labs during pedagogy is consistent with the study by TIMSS (2019), in which the findings show that the majority of students, "56% to 68%" were in classes in which the teacher "never or almost never" used digital tools for science learning. The TIMSS (2019) also revealed that very few students, "5 to 9%", were in classes that “almost use” digital tools for learning daily, which is consistent with the results found in this research in which an average of 3.8% of teachers reported that they “always” use digital devices for

learning. Similarly, a study by George and Kolobe (2014) on the "potential of using a virtual lab for chemistry teaching at secondary school level" indicated that all the respondents were unaware of the existence and availability of web-based digital learning materials and tools for chemistry experiments. Also consistent with the findings of this study (where 69.6% (94) of the teachers do not know where to access virtual lab materials, and 77.1% (104) do not have access to virtual lab resources) is the study done by Folorunso (2018) on "teacher awareness and use of online instructional resources in teaching basic science" which shows that the majority of teachers (86.12%) in Osun State, Nigeria were not aware of the web-based science resources and the bulk of them, (93.06%) reported not having visited any website for teaching resources.

Concerning learners' access to digital devices during pedagogy, the findings of this study are that very few schools, especially in under-resourced schools (quintiles 1-3), have learners that have access to digital devices during teaching and learning. Thus, it is assumed that in some schools, the teacher has to resort to a class demonstration of experiments, where learners are mere spectators. This assumption is based on the difference between the number of teachers who indicated that they use videos and simulations to understand and do experiments (34.1%; 17.0%) and the number of teachers who indicated that their learners use videos and simulations to understand and do experiments (28.1%; 11.9%) respectively. Over and above that, taking into account the following findings from this study: (i) a limited number of schools have laboratories, (ii) of the few schools that have laboratories, most of them are poorly equipped, no basic apparatus and

chemicals, (iii) majority of learners (esp. form quintiles 1-3 schools) do not have digital devices to use during class, it can be concluded with a high degree of certainty that the majority of schools are offering very limited to no experiments at all during science pedagogy. These findings are in agreement with other studies; case in point, a study that was done by George and Kolobe (2014) revealed that very few teachers and student teachers (4%) had done at least ten experiments for the whole year; thus, the great majority of the teachers did very limited to no experiments at all. Furthermore, the same limiting factors coming out of this study were cited, such as lack of laboratories and laboratory resources (George & Kolobe, 2014).

Still, regarding the study done by George and Kolobe (2014), a similar trend to the outcome of this study is observed in the use of videos during pedagogy; very few (13%) of the respondents reported that they used videos during teaching and learning, whereas in this study only 14.8% indicated that they always use videos for teaching and learning.

Comparing the availability of digital resources for use by schools in science classes (62.2% (84) during learning against the number of schools where the science classes frequently engage with these digital resources for learning (3.8%), there is clear evidence that schools are not optimally utilising the digital resources at their disposal for learning. The possible reasons why teachers are not using these digital resources for learning include among other (a) teachers' attitude towards the use of digital devices as effective teaching and learning tools, (b) level of teacher confidence in using these digital resources during pedagogy,

(c) teachers are not aware of the value that comes from using these digital tools, (d) teachers are not trained on how to use them, and (e) teachers lack intrinsic motivation to use them.

There is, therefore, a need for teacher awareness and advocacy campaigns on the use of digital resources, particularly virtual labs in curriculum delivery, followed by training on how to use these digital resources to improve learning outcomes. Based on the study results, which indicated that 69.6% (94) of the teachers do not know where to access virtual lab materials, and 77.1% (104) do not have access to virtual lab resources, it is worth noting that though access to some of the virtual labs materials may need subscriptions, there are a plethora of digital resources among other virtual lab materials available on open sources for free. Therefore, teacher attitude or lack of intrinsic motivation and self-efficacy or lack of awareness of the use of virtual labs or a combination of any of these could be the possible reason(s) why most teachers either do not know where to access virtual lab materials or do not have access to virtual lab resources or both.

Furthermore, regardless of the shortage of digital resources in some schools, predominantly impoverished schools, the findings of this research show that there is massive underutilisation of the digital resources available to teachers. Considering that the research shows that 71.1% (96) schools do have digital devices for teacher use in class; 105 (77.8%) schools have internet connectivity; 61(45.2%) schools have internet speed fast enough to support the use of digital technology during teaching and learning; 55.6% (75) schools provide internet access to teachers to support teaching. However, only 14.8% (20), 0.74% (1) and

7.4% (10) teachers reported that they "always" use videos, animations, and simulations respectively to support science learning. Even if the number of teachers who "usually" use videos [34.1% (46)], animations [17.0% (23)], and simulations [20.7 (28)] were to be considered, the numbers are still low compared to the availability of the resources which still justifies the underutilisation of digital teaching and learning resources.

Also, comparing the availability of digital resources for use by schools in science classes (62.2% (84)) during learning against the number of schools where the science classes frequently engage with these digital resources for learning (3.8%), there is clear evidence that schools are not optimally utilising the digital resources at their disposal for learning. Likewise, based on study results, one may query that if 96 (71.1%) teachers do have digital devices for use in class and 105 (77.8%) teachers have internet connectivity at their schools, how come most of these teachers, 94 (69.6%) do not know where to access virtual lab materials, and 104 (77.1%) do not have access to virtual lab resources given that the there are several open sources where one can access free virtual lab materials. Thus, though access to some of the virtual lab materials may need subscriptions, there are a plethora of virtual lab materials that are available on open sources for free, which begs the question of how come teachers claim they do not know where to access virtual lab materials or do not have access to virtual labs materials?

Based on the aforementioned findings, the possible reasons why teachers are not using or are underutilising these digital resources for learning or does not

know where to access virtual labs materials could be attributed to the same factors mentioned above, including lack of awareness of virtual labs.

Hence the need for teacher training on how to use these digital resources to improve learning outcomes. The use of videos, animations and simulations in science pedagogy is known to enhance learner retention of information, understanding of concepts, improve learner performance, and improve the overall learning experience (Bhattacharjee et al., 2018; Caglar et al., 2015; Estriegana et al., 2019; Lee & Wong, 2014; Penn & Ramnarain 2019; Wen et al., 2020).

Teacher training is one of the aforementioned factors affecting the utilisation of digital resources in science education. This view is supported by the empirical evidence from this study, as indicated by the teacher's level of confidence in using technology in teaching and learning. The results of the study show that the confidence level of the majority of the teachers, 65.9% (89), ranges from "very low" to "medium", with half of them, 34 (50%), indicating that they barely have any technical skills in using technology during teaching and learning. It is also worth noting that the bulk of these teachers, 67.6% (46), are from poor schools (Q 1 -3), whereas the affluent schools account for the majority of the teachers (73.9%) that indicated that they do have "high" to "very high" confidence level in using technology during science pedagogy. Hence the need to train teachers, especially from the poor schools, on how to use technology to support learning. These results correlate to the results on the use of technology in class, in which the bulk of the teachers are not integrating virtual labs into science education

even though they do have access to resources and connectivity, and lack of teacher training could be one of the possible reasons why.

In summary, literature (Banet et al., 2019; Chen & Hu, 2020; Ferraro, 2018; Garba et al., 2015; Hoareau et al., 2021) has shown that the integration of Information and Communication Technology (ICT), including digital technology into education has a positive impact on student learning outcomes. According to Ferraro (2018), ICT integration in education is the basis for imparting and improving technology-related competencies in students. Similarly, Ferraro's (2018) study indicates that ICT use during pedagogy resulted in improved learning and knowledge acquisition among students. Furthermore, as reported by Hoareau et al. (2021), on the research done by Xie et al. (2018) on the use of digital technology in class revealed improved learning outcomes when tablets are integrated into teaching and learning compared to the conventional approach. Regrettably, the results from this study indicate (a) that most teachers across all quintiles are neither aware of nor are using virtual labs during pedagogy (b) majority of learners and teachers from poor schools (Q 1 – 3) do not have digital devices to use during class, (c) there is massive underutilisation of the digital resources available to teachers and (d) majority of the teachers, predominantly from under-resourced schools (Q1-3) have low confidence level in using technology during teaching and learning.

Therefore, this study's findings agree to a greater extent agree with the second proposition that teachers are not aware of the availability and value that can be

derived from virtual labs and hence are not using this technology (VL) in science education.

The following section is a discussion of the results under the third proposition.

5.5 Discussion pertaining to proposition 3

Proposition 3: *The use of virtual labs in science pedagogy improves learning outcomes, among other, learner achievements.*

The results of the study on the "use of virtual labs in class" section reveal that most of the schools, 75.6% (102), do not use virtual labs for teaching and learning. Based on the nature of results from the previous sections of this study, it is not surprising to point out that almost all (96.1%) of the quintile 1 -3 schools do not use virtual labs for teaching and learning and yet, surprisingly enough, most (60.8%) of the quintile 4 and 5 schools are also not using virtual labs for learning. Since most quintile 4 and 5 schools are ordinarily better resourced and are in a better position to acquire the necessary resources, if need be, the number of schools using virtual labs is lower than anticipated. Of the 33 (26.2%) schools that use virtual labs, the majority, 75.8% (25), are from secondary schools.

Of the limited number of schools, 33 (26.2%) reported using virtual labs. Different levels of value derived from integrating virtual labs into science education, ranging from no noticeable change, slight improvement, and significant improvement, have been reported, as illustrated in Figure 11.

There is a plethora of empirical evidence from various studies that are consistent with the findings of this study on the value derived from the integration of virtual labs in science education. Studies by Hodges et al. (2018), Li et al. (2020), and Penn and Ramnarain (2019) show that virtual labs improve the learner's level of understanding of science concepts and experiments, which is in agreement with the results of this study in which 33.3% (11) of the teachers reported a slight improvement and 57.6% (19) a significant improvement in their learner level of understanding of science concepts and experiments ever since they started using the virtual lab for teaching and learning. In their studies, Penn and Ramnarain (2019) revealed that virtual laboratories aid in understanding chemistry concepts better than traditional laboratories. It is worth noting that Penn and Ramnarain (2019) work shared the same context as this study (all done in SA). In the case of Hodges et al. (2018), high school students' understanding of redox reactions was investigated using a blended approach of traditional and virtual labs. Similar to this study, Hodges et al. (2018) revealed that virtual labs resulted in improved student understanding of science key concepts (redox reaction). In addition to improving learners' level of understanding of subject concepts, the study findings by Li et al. (2020) also support the findings of this study that use virtual labs during pedagogy cultivate learner interest in the subject. In this study, according to 36.4% (12) of the teachers who are using virtual labs during teaching and learning, a significant improvement in their learner level of overall interest in science subjects has been observed, while 51.5% (17) reported having observed a slight improvement. In the case of Li et al. (2020), they used a virtual 3D environment to explore the effect of simulations on students' spatial ability. Just

as in this study, the authors draw three crucial findings, they found that virtual 3D environments (i) offer learners better mastery and understanding of subject concept knowledge compared to traditional learning materials, (ii) create and nurture enthusiasm and interest in learners in the subject, and (iii) provide a good user experience.

The empirical findings from the above studies are strongly supported by the theory that the use of virtual environments in learning provides a powerful sense of reality in learners, which aids them in exploring various problems – the most effective inquiry-based learning model there is (Li et al., 2020; Penn & Ramnarain 2019; Wen et al., 2020). Thus, by leveraging the power of digital technology, in this case, virtual labs, to support 21st-century learning skills, learners are afforded the opportunity to (a) own and drive their learning, (b) be creative and develop critical thinking skills needed to solve complex problems, (c) communicate and collaborate and (d) realise the practical relevance of science through an adventurous learning experience, thus fostering interest and the love for science in learners (Bhattacharjee et al., 2018; Caglar et al., 2015; Estriegana et al., 2019; Lee & Wong, 2014; Li et al., 2020; Penn & Ramnarain 2019; Philippe et al., 2020; Wen et al., 2020).

Considering the effect of virtual labs on learner performance and achievement, the results of this study concur with the results of the similar studies by Bhattacharjee et al. (2018), Hodges et al. (2018), Lee and Wong (2014), and Wen et al. (2020) in which the use of virtual laboratories in science pedagogy yielded greater achievement in learning outcomes in students compared to the traditional

teaching and learning approach. Furthermore, similar to Penn and Ramnarain's (2019) findings, the study by Hodges et al. (2018) also shows that students exposed to a blend of virtual and traditional labs outperformed students exposed to traditional labs only. In this study, 45.5% (15) of the teachers reported a slight improvement and 36.4% (12) a significant improvement in their learner level of performance and achievement in the science ever since they started using the virtual lab for teaching and learning. In their study, Lee and Wong (2014) investigated the impact of using virtual reality-based learning methodology on students with different spatial abilities based on a concept in biology – dissection, while in the case of Bhattacharjee et al. (2018), they investigated the impact of the immersive virtual lab model on learning using biology and chemistry topics across three case studies, (i) learners without any learning disorders, (ii) learners with "Attention Deficit Hyperactivity Disorder (ADHD) and (iii) learners with "Audio Processing Disorder (APD)". In all the studies and cases, the integration of virtual labs in science education was found to improve learning outcomes.

With regards to learner knowledge retention of science concepts, the outcomes of the study by Wen et al. (2020) proved that virtual labs foster long term retention of science facts, skills, and knowledge in learners (which are all essential elements in the learning process) compared to conventional teaching and learning approach. In this study, 57.6% (19) of the teachers indicated a slight improvement, and 30.3% (10) observed a significant improvement in their learner level of knowledge retention of science concepts and experiments ever since they started using the virtual lab for teaching and learning. In addition to that, Wen et

al.'s (2020) study results also proved that using virtual reality-based learning approaches has a positive impact on the students' scientific literacy.

Moreover, the findings of a review of 56 empirical research studies by Brinson (2015) on "learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories" are in line with the findings of this study and other several empirical research outcomes (Hodges et al., 2018; Penn & Ramnarain, 2019). The review has shown that most of the studies show an overall higher student learning achievement in the experimental group (exposed to virtual labs) compared to the controlled group (confined to traditional labs) in several areas, including, among others, scientific inquiry and practical skills, conceptual understanding and knowledge of science subjects and analytical skills.

With respect to the effect of virtual labs on collaboration and teamwork among learners and learner engagement and participation during classes, the study results are consistent with the ones presented in Lorusso et al. (2020). Based on the results illustrated in Figure 11, 51.5% (17) of the teachers observed a significant improvement in their learner level of engagement and participation during classes ever since they started using the virtual lab for teaching and learning, while 36.4% (12) reported a slight improvement. On the other hand, 24.2% (8) teachers reported significant improvement in their learner level of collaboration and teamwork among learners ever since they started using the virtual lab for teaching and learning, while 45.5% (15) teachers attested to a slight improvement. In their study, Lorusso et al. (2020) reported high participation,

cooperation and interaction among learners when using a semi-immersive virtual reality system as a teaching and learning tool. In addition, improved comprehension of tasks among learners was also stated as one of the findings of their study.

Taking into consideration "teaching and learning experience" as a parameter to measure the value of virtual labs in supporting education, the results of this study are supported by Zhou et al. (2018), and Girvana and Savage (2019)'s findings. The findings of the study by Girvana and Savage (2019), in which they explored the concept of constructionist learning using virtual environments, revealed that virtual environments provide an improved learning experience. Their study showed that learners were able to construct "meaningful artefacts and through their construction learners were able to explore, test and extend their understanding of programming" (Girvana & Savage, 2019, p. 408). In this study, 54.5% (18) of the teachers reported that ever since they started using the virtual lab for teaching and learning, there was a significant improvement in their learner level of overall learning experience, while 42.4% (18) reported a slight improvement.

Overall, the findings from the self-reported data in this study are seamlessly supported by diagnostic assessments based on quasi-experimental design research studies by Bhattacharjee et al. (2018), Lee and Wong (2014), Penn and Ramnarain (2019), and Wen et al. (2020) in which the experimental group interacted with virtual learning resources through the virtual lab, while the control group was subjected to the conventional classroom learning approach. In all the

studies, the outcome of the diagnostic assessments (pre and post-test) displayed a remarkable improvement in learner performance in the experimental group relative to the learners from the control group. The findings of this study are also consistent with the aforementioned study findings that revealed that the use of virtual labs improves learners' understanding of the science phenomena by (a) bridging understanding gaps in conceptual knowledge, (b) providing a better explanation of concepts through visuals and simulations, (c) providing an environment that mimics reality for science inquiry-based learning, (Bhattacharjee et al., 2018; Estriegana et al., 2019; Hodges et al., 2018; Lee and Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020). Furthermore, by providing instant feedback on experiments and assessment exercises in real-time, virtual labs offer learners the opportunity to make multiple changes to their work or go back and redo the experiments or assessments to develop their scientific skills better and grasp the concepts better.

In summary, regardless of the limited number of schools, 33 (26.2%) utilising virtual labs for science pedagogy, the results of this study, supported by several empirical research-based studies, revealed that integration of virtual labs into science education does offer far-reaching value and benefits in terms of improved learning outcomes which include but not limited to, provision of a conducive learning environment that promote active learner participation (inquiry-based learning) and creation of both personalised and collaborative interactive learning environments for learners (Bhattacharjee et al., 2018; Lee & Wong, 2014; Makransky & Petersen, 2019). All of which lead to improved learning outcomes:

acquisition and long-term retention of science facts, skills, and knowledge; an improved learning experience and learner achievements; and above all, cultivating learner interest in science, hence higher chances of pursuing STEM field subjects and careers (Bhattacharjee et al., 2018; Coenen et al., 2021; Kennedy & Odell, 2014; Lee and Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020).

Therefore, based on the results of the schools that are integrating virtual labs into science education, the findings of this study agree with the third proposition made that the use of virtual labs in science pedagogy improves learning outcomes, among other learner achievements.

5.6 Chapter overall discussion

This section is an overall discussion of the study results based on the three propositions made. It consolidates and summarises the findings from each of the three propositions, outlining how they link or relate. It also highlights any trends or patterns observed among the constructs across the three propositions relating to no-fee schools (quintiles 1-3) and fee-paying schools (quintiles 4&5).

With information from teachers, the survey results add to the already existing extensive body of research showing a robust positive correlation between schools' socioeconomic environment and resources availability and accessibility, both scientific and digital. Generally, the study results show that poor schools (Q 1-3) do not have adequate basic resources to support learning, which is the opposite of affluent schools (Q 4 and 5). For instance, with regards to teacher

access to digital devices, of the 28.9% of the schools that indicated that they do not have computers/laptops for teacher use, the majority of them, 82.1%, are from quintile 1-3 schools, and of the 46.7% (63) that have projectors for lesson delivery, the majority 76.2% are quintile 4 and 5 schools and only 12.7% from quintile 1-3 schools. Thus, most schools from low socioeconomic status communities do not have the basic digital resources, i.e., computers and projectors for lesson delivery. Literature (Garba et al., 2015) regards a combination of a computer and projector as the basic components needed for the basic level of ICT integration in pedagogy. Projecting science images, video clips, animations, and simulations make "learning more meaningful and concrete" by allowing learners to witness the practical applications and relevance of the theory taught (Garba et al., 2015). Hence, at the very least, each school must have these two basic resources to ensure teachers concretise science learning; otherwise, science learning will remain abstract, and rote based.

Alternatively, mobile learning can be implemented, especially in poor schools. Research (Akçayir et al., 2016; Chen & Tsai, 2020; Liu et al., 2021; Mwapwele et al., 2019; Padayachee, 2017) has shown that mobile phones can be effectively used for digital learning without the restriction of time and location. Thus, learners can still utilise them for learning even if they are at home or during the night. Furthermore, the availability of digital resources and internet connectivity to the learner at all times (24/7) can be exploited to facilitate a blended learning approach, especially for the higher grades that would offer greater returns in terms of improved learning outcomes. The access to virtual lab materials through

smartphones implies that learners can have more autonomy in driving their learning, increased learner engagement with the subject content, increased remote and virtual collaboration among learners, more effective use of contact time, and increased sharing of information among learners (Bhattacharjee et al., 2018; Caglar et al., 2015; Chen & Tsai, 2020; Estriegana et al., 2019; Lee & Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020) to mention but a few benefits among many. Unfortunately, according to research by Mwapwele et al. (2019), most South African schools forbid the use of personal phones during school hours.

The same trend is observed with internet accessibility; the survey shows a correlation between schools' socioeconomic status according to the school poverty ranking and internet accessibility. Though some of the poor schools (Q1-3) do have internet, it is either the connectivity is unstable, or the speed is not fast enough to support digital learning (downloading or use of videos, animations and simulations), and in some instances, the internet is not for teaching and learning purposes. In comparison, the opposite is true for most affluent schools. This pattern is seen throughout all the constructs considered in this study. For example, the results on the extent of use of digital technologies among other science videos, animations and simulations in supporting science education by teachers indicate that a relatively high percentage of teachers from affluent schools (Q4 and 5) do integrate these technologies into teaching and learning. In contrast, teachers from poor schools hardly do so. The same applies to the

learner's extent of engagement with these digital technologies during learning in affluent schools versus poor schools.

The effect of the socioeconomic environment in which the schools belong can then be said with a high degree of certainty that it has resulted in a cascading effect with catastrophic consequences on the overall learning outcomes in science subjects predominantly manifesting in poor schools. Thus, inaccessible or poor internet connectivity and lack of scientific and digital resources lead to abstract teaching and learning, which results in poor learning outcomes, including, among other things, learner achievement in science subjects. This theory is strongly supported by a plethora of empirical research study outcomes (HRSC, 2019; Letsoalo et al., 2019; Pournara, 2020; TIMMS, 2019), which have proven that the extent of learner academic performance and achievement is significantly dependent on the availability of teaching and learning resources among other factors. Study results from Pournara (2020) and HRSC (2019) have shown a similar trend where learners from well-resourced schools (Q 4 and 5) achieved higher scores than learners from under-resourced schools (Q 1 – 3). The TIMMS (2019) study also reported a positive correlation between science student achievement and the use of digital resources in class. The authors attributed higher achievements in students exposed to digital learning to having access to various resources that helps them understand concepts better.

Therefore, the socioeconomic status of the school's community remains one of the key parameters that account for the variation in learner achievement across quintiles (Letsoalo, 2017). That being said, it is a pity that the majority of the

learners, roughly 79% (nationally), are in quintiles 1 – 3 schools (poor and under-resourced) (DBE, 2017), which explains why South Africa has repeatedly been underachieving in all the international assessments (TIMSS) that the country participated in, in maths and science subjects ever since 1995 to 2019 (HSRC, 2015; HSRC, 2019; TIMMS, 2020).

Thus, in a much broader sense, the socioeconomic status of communities can directly or indirectly lead to a vicious cycle of poverty in poor communities and a virtuous cycle in affluent communities, which in turn affect the schools located in them accordingly.

This study shows that most schools do not have the scientific infrastructure or functional laboratories due to a shortage of equipment and non- replenishment of consumables; hence, most schools do not perform science experiments during teaching and learning. Furthermore, literature has alluded to the effects of abstract teaching and learning approaches in science, including poor learner understanding of concepts, disruptive behaviour during class, poor learning outcomes, boredom, and absent-mindedness (Banet et al., 2019). Thus, the Department of Basic Education can circumvent all these challenges caused by the lack of scientific infrastructure by integrating virtual labs into science pedagogy in schools. Literature has already proved that this approach is feasible and bears several benefits. These benefits include among other, but not limited to, (i) easy access to a wide range of delivery approaches (video, imagery, audio) and learning materials related to each topic, which all can be seamlessly integrated into a lesson to cater for a wide variety of learners with different types

of learning abilities and conditions such as like Autism Spectrum Disorder, Audio Processing Disorder (APD) and "Attention Deficit Hyperactivity Disorder ADHD (Bhattacharjee et al., 2018); (ii) real-time feedback and personalised learning, allowing teachers pick up individual learner struggles in real-time and attend to individual needs of the learners thereby ensuring no learner is left behind; (iii) virtual labs offers learners limitless opportunities for repetition (of experiments, and assessments) from which they can greatly benefit at absolutely no extra costs; and (iv) increases the chances for peer collaboration among learner (Bhattacharjee et al., 2018; Lee & Wong, 2014; Makransky & Petersen, 2019).

Emerging from the study is also the underutilisation of scientific and digital resources by schools. Resource underutilisation in this context refers to both frequency in terms of use and the degree (depth) to which teachers use these resources. Based on the study results (Table 6 – the extent of use of virtual labs by teachers in class), underutilisation of resources with respect to the extent to which schools are exploiting the potential and possibilities offered by digital technology in improving science education can be said to be an issue across all quintile schools, both poor and affluent schools. According to the survey results, of the teachers [98 (72.6%)] that integrate digital technologies in learning, all of them (100%) use these resources to access science videos which is the lowest level of utilising the resources. Very few, 33 (33.7%) of the teachers use the digital resources for high-level learning, simulations ("usually & always" category). The results from the same Table 6 also show that the frequency of use of these

resources is extremely low in the majority of the schools, especially quintiles 1-3 schools.

The findings of this study on the resource underutilisation in Gauteng public schools in terms of the extent of leveraging the potential and possibilities offered by digital technology in improving science education are strongly supported by Banet et al. (2019). The author pointed out that there was a general agreement that European secondary schools fall in a similar dilemma of not yet at a stage at which they are fully utilising digital technologies to yield optimum benefits in education delivery, including improved learning systems. As the scenario in this study, Banet et al. (2019) pointed out that inadequate supply of ICT infrastructures and lack of other suitable teaching and learning resources are some of the main drivers behind the underutilisation of digital technologies in schools. Underutilisation of resources could also be attributed to a lack of technical knowledge and skills to use them and a lack of confidence in using technology during pedagogy (as indicated in this study that some teachers have a low confidence level in using technology during teaching and learning). Advocacy and teacher training on using digital technology (virtual labs) to support science education are crucial undertakings to overcome the aforementioned challenges. However, besides lack of or low confidence and technical skills to implement digital technology in learning, there are issues of teacher attitude and low intrinsic motivation and self-efficacy towards technology-based teaching and learning.

For sustainable systemic integration of digital technologies (e.g., virtual labs) in education, the need for formal policies that enforce its implementation by teachers in schools cannot be overemphasised. In South Africa, several policies on integration of ICT in pedagogy have been passed on since 2004. These include, among others, (a) the White Paper on e-Education of 2004 (DBE, 2012), (b) the DBE Action Plan to 2024, with one of its priorities focusing on coding and robotics (DBE, 2020), and Operation Phakisa which focuses on devices, connectivity, teacher professional development, and curation of digital content. However, to date, all these policies have not achieved much in terms of implementation in schools due to several challenges, including the lack of basic ICT and digital infrastructure and lack of ICT and digital skills among teachers (Padayachee, 2017). What came out of Padayachee (2017)'s study was that the "teachers are uncertain concerning the enforcement of e-education policy", which concurred with Vandeyar (2015) as referenced by Padayachee (2017), indicating a lack of practical enforcement of the policies, hence leaving the adoption and integration of digital technologies in teaching at the teacher's discretion. Therefore, the implementation of digital technology will depend entirely on teacher attitude, their extent of intrinsic motivation and self-efficacy towards the use of digital technologies in teaching and learning.

Thus, the South African schooling system, among other nations, has not yet realised the full benefits and value that digital technology can bring to the education space due to a lack of functional structures that ensure practical enforcement of policies, formally mandating the integration of digital technologies

into teaching and learning by schools. If to be formulated, such a policy should include, among others, digital resource provisioning, continuous professional development and support for teachers on how to use these resources, and monitoring of the use of these digital resources at the classroom level. Lastly, the schools should be held accountable for the non-use of these resources. At the moment, it seems that the implementation of digital technologies in learning is left to the discretion of schools and teachers which the results of this study have shown*, firstly*, that teachers are not utilising these digital resources even if they are available in schools and *secondly*, teachers are underutilising these resources. These findings are supported by recent literature (Banet et al., 2019) that revealed that the "potential of new ICTs to provide the students with the skills necessary for the future has not yet been fully embedded". It is, therefore, imperative to instil and foster lifelong digital skills in learners through practical applications as they go through their daily learning by having a schooling system that fully integrates digital technologies into science teaching and learning, not the current pick and choose scenario that we are having.

However, as noted by Chen et al. (2014), these digital technologies, in this case, virtual labs, are not to be considered a silver bullet; nor a "cure" to all curriculum-related ills that will magically improve learning outcomes in learners. The reality is that it takes changing behaviours, beliefs, (Makransky & Petersen, 2019), attitudes and values, to mention but a few, for both teachers and learners to use digital technologies in learning and build much more positive ones. Otherwise, without intrinsic motivation or changed mindsets, attitudes and beliefs of the users

and consumers, in this context, teachers and learners on the use of the digital technologies in learning, even if best implementation frameworks are put in place, not much has to be expected in terms of change (improvement) in learning outcomes. In other words, the users and consumers have to "believe" in the technology to yield optimum benefits and value, as indicated by empirical evidence from research (Chen & Hu, 2020; Makransky & Petersen, 2019). In support of the aforementioned argument on the need for intrinsic motivation in learners and teachers if the full potential of digital technologies (virtual labs) is to be realised, in their studies, Chen and Hu (2020) found a strong positive correlation between learners' “interest in ICT and their ICT self-efficacy”. Furthermore, the authors pointed out that learners' self-efficacy in manipulating ICT significantly contributes to their ICT literacy level as well as academic achievement.

One more aspect that needs to be brought to the fore is that even though research (Bhattacharjee et al., 2018; Lee & Wong, 2014; Makransky & Petersen, 2019) has shown that inquiry-based learning is at the core of learning in science subjects, literature reported that most of the science curriculum globally are expository by design (Brinson, 2015), of which the South African science curriculum is no exception. Thus, regardless of whether schools have functional laboratory facilities, science education remained teacher centred. Not to mention that based on its design (expository), the approaches, procedures, and steps to be followed in any lab activities are prescribed to the learners, with the teacher acting as the instructor or supervisor. Thus, in essence, learners are made to

repeat already well known, firmly established and proven scientific principles and theories under strict and well-defined instructions, thus, working towards solutions, deductions or answers they already know. However, scientific literature (Brinson, 2015) has pointed out some of the major shortfalls of such approaches, such as (a) not affording learners the opportunity to think critically, being creative and innovative in solving the problem, (b) depriving learners the opportunity and experience to "create their own understanding of the phenomena they are investigating" (Brinson, 2015), and (c) limiting the overall learner scientific discovery journey to already known theories and scientific processes, thus denying students an opportunity to contribute to the scientific knowledge or think beyond the existing scientific knowledge and theories or at least question them.

With the emergence of digital technologies, among other virtual labs, science learners and students can now break away from the chains of rote learning. Digital tools in science learning have afforded learners and students the opportunity to self-learn, create their own understanding of scientific concepts through exploration and experimentation beyond testing known theories, test the limits of science, do harmful and dangerous experiments at absolutely zero risk, repeat experiments and use expensive and sophisticated instrumentation multiple times without any cost implications (Bhattacharjee et al., 2018; Lee and Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020).

CHAPTER 6. CONCLUSIONS & RECOMMENDATIONS

6.1 Introduction

The value and benefits of digital technologies in education cannot be overemphasised. Empirical based studies (Philippe et al., 2020; Akçayir et al., 2016; Frank and Kapila, 2017; Guan et al., 2020; Roll & Wylie, 2016) have proven that digital technology-based teaching and learning methodologies, which include, among other virtual labs (Banet et al., 2019; Bhattacharjee et al., 2018; Estriegana et al., 2019; Lee & Wong, 2014; Penn & Ramnarain 2019; Wen et al., 2020), have great potential of improving learning outcomes while providing learners with a great learning experience.

However, the effective integration of digital technologies into education has its demands that most institutions of learning (schools) are still battling to meet. For instance, effective implementation of virtual labs in science subjects requires basic digital and scientific infrastructure, adequate learner and teacher resources to be in place, and stable internet connectivity. Teacher preparation to implement the methodologies during pedagogy will be the next phase. Thus, this is a multi-phase process that requires, among other things, advocacy and awareness campaigns on the use of digital technologies to support learning, changing mindsets and attitudes, building new behaviours, instilling self-efficacy in teachers towards the use of digital technologies in education before training them on how to implement the methodologies.

To this end, this study sought to establish the state of integration of virtual labs in science education in South African public schools, focusing on selected schools in Gauteng province. Guided by three research questions that sought to, *firstly*, find out the constraints faced by teachers in the current methodologies used in science education, *secondly*, establish the extent to which science teachers are aware of and are using virtual labs in supporting science education and *thirdly*, establish the value that teachers have experienced and observed ever since they started integrating virtual labs into teaching and learning of science subjects, the findings from the study are summarised below.

6.2 Conclusions regarding research question 1

With regards to the constraints faced by teachers in the current methodologies used in science education, the overall findings are that there is an acute shortage and, in some cases lack of necessary scientific, digital and internet infrastructures to support science education in schools located in poor communities (quintile 1 - 3 schools). Contrary to the findings from quintiles 1 – 3 schools, the survey results indicated that most rich schools (Q 4 and 5) have these infrastructures. These findings are supported by several studies (HSRC, 2019; TIMSS, 2020; van Dyk & White, 2019), which indicated that affluent schools (Q 4 and 5) are by far much better resourced than poor schools (Q1- 3). The shortage or lack of the necessary basic scientific and digital infrastructure has an adverse effect on the quality and standard of curriculum delivery of maths and science subjects and, ultimately, the learning outcomes (especially for poor and under-resourced schools) as reported in studies (HRSC, 2019; Letsoalo et al., 2019; Pournara, 2020; TIMSS, 2020).

Hence, the extent to which a school is resourced contributes to the ultimate level of learner performance. In other words, in the south African context, where there is a strong correlation between the school quintile rank and level of resourcing, the socioeconomic status of the community in which the school is located remains one of the key factors that account for the variation in learner performance across quintiles (Letsoalo, 2017; Pournara, 2020).

Therefore, the findings under the first research question are in alignment with the proposition made that constraints faced in the current methodologies used in science education are contributing to poor learner performance in science in South African public schools.

6.3 Conclusions regarding research question 2

Although many scholars (Ferraro, 2018; Hoareau et al., 2021; Garba et al., 2015; Chen and Hu (2020); Banet et al., 2019) have proved through empirical evidence that the integration of digital technologies into education has a positive impact on student learning outcomes, regrettably, the study findings on the second research question show that irrespective of the shortage of digital resources in some of the schools, there is a massive non – utilisation and underutilisation of the available digital resources in schools. Furthermore, the results indicated that the non – utilisation and underutilisation of the available digital resources are predominant in quintiles 1 – 3 schools. The non-utilisation and underutilisation of resources can be attributed to the following reasons but are not limited to, (a) lack of teacher awareness of the existing web-based teaching and learning digital materials, (b)

teachers' attitude towards the use of digital devices as an effective teaching and learning tools, (c) level of teacher confidence and self-efficacy in using these digital resources during pedagogy, (c) teachers are not aware of the value that comes from using these digital tools, (d) teachers are not trained on how to use them, and (e) teachers lack intrinsic motivation to use them.

Hence the need for teacher awareness and advocacy campaigns on the use of digital resources, particularly virtual labs in curriculum delivery, followed by training on how to use these digital resources to support and improve learning experience and outcomes.

Further findings from the study under this research question also indicate (a) that most teachers across all quintiles are neither aware of nor are using virtual labs during pedagogy (b) majority of learners and teachers from poor schools (Q 1 – 3) do not have digital devices to use during class, and hence it can be assumed that in such schools the learners are not exposed to experiments at all or the teacher has to resort to class demonstration of experiments where learners are mere spectators, (c) majority of the teachers, predominantly from under-resourced schools (Q1-3) have low confidence level in using technology during teaching and learning - indicating that they barely have any technical skills in using technology during teaching and learning.

Therefore, the findings of this study support the second proposition that teachers are not aware of the availability and value that can be derived from virtual labs and hence are not using this technology (VL) in science education.

Over and above that, taking into account the following findings from this study: (i) a limited number of schools have laboratories, (ii) of the few schools that have laboratories, most of them are poorly equipped, no basic apparatus and chemicals, (iii) majority of learners (esp. form quintiles 1 – 3 schools) do not have digital devices to use during class, it can be concluded with a high degree of certainty that the majority of schools are offering very limited to no experiments at all during science pedagogy.

6.4 Conclusions regarding research question 3

Regarding the third research question, the results of this study, supported by several empirical research-based studies, revealed that the integration of virtual labs into science education does offer far-reaching value and benefits. These include improved learning outcomes which include but are not limited to the provision of a conducive learning environment that promotes active learner participation (inquiry-based learning), and creation of both personalised and collaborative interactive learning environments for learners (Bhattacharjee et al., 2018; Lee & Wong, 2014; Makransky & Petersen, 2019). All of which resulted in improved learning outcomes: acquisition and long-term retention of science facts, skills, and knowledge; an improved learning experience and learner achievements; and above all, cultivating learner interest in science, hence higher chances of pursuing STEM field subjects and careers (Bhattacharjee et al., 2018; Coenen et al., 2021; Kennedy & Odell, 2014; Lee and Wong, 2014; Penn & Ramnarain, 2019; Wen et al., 2020).

However, the study results indicated that only a small percentage of the teachers, 26.2% (33), use virtual labs to support science education. Regardless of the limited number of teachers utilising virtual labs for science pedagogy, these schools should be applauded since, based on the desktop research done, there has been neither a formal awareness campaign for the adoption of VL in science education nor teacher training on the initiative. Teachers from these schools are doing it entirely out of their own volition, a sign of self-motivation, and pure interest in science, since there is a lack of practical enforcement of the policies (Padayachee, 2017) hence leaving the adoption and integration of digital technologies in teaching at the teacher's discretion.

Based on the results from the schools that are integrating virtual labs into science education, the findings of this study concur with the third proposition made that the use of virtual labs in science pedagogy improves learning outcomes, among other, learner achievements.

6.5 Recommendations

Given (i) the shortage of scientific and digital infrastructure to support science education in the system, (ii) teacher ignorance and unawareness of the existence of web-based digital teaching and learning materials at their disposal for use during pedagogy, (iii) the non – utilisation and underutilisation of available digital resources, (iii) low teacher level of confidence and self-efficacy in using digital technologies in teaching and learning, (iv) the value and potential that virtual labs have in improving learning experience and outcomes, (v) the benefits and

advantages that virtual labs have over traditional labs, the following is recommended to promote the integration of virtual labs in science education:

1. Advocacy & communication campaigns on the use of virtual labs in pedagogy that will include, among other aspects but not limited to, (i) building awareness of the value and benefits of virtual labs in science education, (ii) changing departmental officials and teacher mindsets, attitudes and behaviours towards the use of virtual labs in education, (iii) building self-efficacy of teachers towards the use VL to support science education. The advocacy campaigns and dialogues are envisaged to build up to a national conversation on the aforementioned themes, leading to further studies in this area. Just like the findings from other studies such as Progress in International Reading Literacy Study (PIRLS) and TIMSS, that resulted in literacy (Early Grade Reading Study- EGRS) and numeracy (Early Grade Mathematics Project - EGMP) being made both national and DBE priorities, given the shortage of scientific infrastructures in most schools, such conversations and dialogues may lead to the adoption of virtual labs as a better and cost-effective alternative to address not only the learning gaps due to lack of traditional laboratories but also some of their limitations.
2. Capacitation of educational officials at provincial, district, and school levels on integrating virtual labs into science education. To ensure sustainability, a cascading model for Continual Professional Development (CPD) should be adopted, where provincial and district officials (circuit managers, subject advisers, facilitators) are trained and capacitated on the use and integration

of ICT and virtual labs in education, who will subsequently train and support teachers on an ongoing basis.

3. There is also a need for the integration of ICT into pre-service teacher preparation education programs (Padayachee, 2017) to build the necessary skills and competencies, confidence and self-efficacy in the use of digital technologies during pedagogy before they start practising.
4. The study findings indicate the non-utilisation and under-utilisation of digital devices in schools. To ensure full utilisation of the existing digital devices by schools, the DBE and PEDs should put in place functional structures, e.g., policies, which ensure practical enforcement of the integration of digital technologies during science pedagogy. In addition, provincial and district officials will monitor the use of these digital resources at the classroom level, holding schools accountable for the non-use of these resources.
5. Leverage "bring your own device" (BYOD) to schools (Padayachee, 2017) to integrate virtual labs in teaching and learning, providing an opportunity for learners to actively engage and participate in their own learning even remotely. To that end, the DBE should pass legislation that forbids schools from banning the use of learners' own devices during school and in class. Such an initiative may go a long way in alleviating the acute shortage of digital devices in schools, especially in poor and under-resourced schools.

6.6 Conclusion

As indicated in section 1.1, the purpose of the study was to investigate the extent of integration of virtual labs in supporting science education in selected South African public schools for improved learning outcomes. Thus, the purpose consists of two parts: Firstly, the extent of integration of virtual labs in supporting science education in schools and, secondly, the improvement in the learning outcomes in science subjects. In this study, "extent" was considered in the context of the percentage of schools/teachers using the virtual lab concept and the frequency of use of VL in teaching and learning, where the frequency is defined in terms of "non-use, seldomly, usually and always."

Firstly, considering the extent of use of VL in learning with regards to the percentage of schools, the findings from the study clearly indicate that the majority of the teachers in the sampled schools, 73.8% (93), are not using virtual labs for teaching and learning of science subjects, of which most of them are from quintiles 1-3 schools. In comparison, almost all (96.1%) of the quintiles 1-3 schools that participated in the study do not use virtual labs for teaching and learning, relative to 60.8% of the quintiles 4 and 5 schools. Furthermore, the "extent" with regards to the frequency of use of VL in teaching and learning is extremely low, with the majority, 57.8%, of the teachers reporting that they never used simulations (VL), and an average of 17.1%; 18.9%; and 4.5% reporting that they seldomly, usually and always use VL in science learning respectively. The affluent schools (Q 4 and 5) reported better results in all the categories compared to poorly resourced schools (Q1-3).

Secondly, in terms of improvement of the learning outcomes, of the limited number of schools, 33 (26.2%) that reported to be using virtual labs, the results of this study revealed a general improvement in the acquisition and long-term retention of science facts, skills, and knowledge; improved learning experience and learner achievements; and above all an improvement in cultivating learner interest in science, hence higher chances of pursuing STEM field subjects and careers in future.

Therefore, it is clear that the extent of integration of VL in supporting science education is extremely low and differs according to the socioeconomic status of the community in which the school is located (measured as school quintile ranking) (Letsoalo, 2017). Furthermore, given that very few schools are using the VL in learning, 33 (26.2%), this is likely to have a negative impact on the overall improvement in science learning outcomes at a systemic level (national/provincial). The study, therefore, makes valuable contributions towards alleviating this national problem.

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APPENDIX A: Research Survey Questionnaire

Link to the online survey questionnaire:
https://docs.google.com/forms/d/e/1FAIpQLScbyxFOs4FL0vraRYvD5u2FSq04UzlQqDHl-53uxTKhmErg-Q/viewform?usp=sf_link

Below is the electronic version of the questionnaire

Integration of virtual labs into science education in Gauteng

Dear Potential Participant

Good day, my name is Godwin Nhauro, and I am a master's student in Digital Business at the University of the Witwatersrand (Wits University), Johannesburg. As part of my studies, I have to undertake a research project, and I am conducting research on the use virtual labs (computer – based science simulations/activities) in science education at selected public schools in Gauteng under the supervision of Prof Rene Pellissier. The aim of this research project is to the find out the extent to which science teachers are aware of the use of virtual labs in supporting science education, the extent to which they are using this digital technology, and the value derived from using them.

As part of this project, I would like to invite you to take part in an answering a questionnaire. This activity will involve you answering multiple choice questions via an online form and will take around 8 - 15 minutes.

There will be no personal costs to you if you participate in this project, You will not receive any direct benefits from participation but there are no disadvantages or penalties if you do not choose to participate or if you withdraw from the study. You may withdraw at any time. The questionnaire will be completely confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. If you wish to receive a summary of this report, I will be happy to send it to you. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za

Thank you for considering participating in this research project.

The questionnaire can be accessed on the next page and by joining you are giving full consent to participate in this research project.

Yours sincerely,

Researcher: Godwin Nhauro,

Email: 335422@students.wits.ac.za

Supervisor: Prof Rene Pellissier,

Email: rene@pellissier.co.za

Informed consent as a participant

☐ I have read and understood the terms and the extent of my participation, and I voluntarily agree to participate in this study.

Section A: Teacher/School Background information

1. Please note, Science in this questionnaire refers to any or a combination of the following subjects: Natural Science and Technology (NS/Tech), Natural Science (NS), Physical Science, Life science and/or Biology.
   a) Are you a science teacher?

   Yes O No O

   b) Are you currently teaching science?

   Yes O No O

   c) Are you servicing a primary, combined, or secondary/high school?

   Primary O Combined O Secondary/High O

   d) Which phase do you teach, or have you taught before? Select all that are relevant.

Intermediate Phase (IP)	Senior Phase (SP)	FET Phase
O	O	O

e) What quintile does your school fall under?

Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	I don't know
O	O	O	O	O	O

2. Section B: The constraints faced in the current methodologies used in science education *(Delimitations: Research will only focus on the availability of 1.1 power supply, 1.2 Internet connectivity, and 1.3 Resources: laboratory and digital -based resources)***.**

2.1 Do you have power supply at your school?

Yes	No
O	O

2.2 Please indicate internet accessibility at your school:

		Yes	No	I don't know	N/A
a)	Do you have internet connectivity at your school?	O	O	O	O
b)	Is the internet connectivity stable and reliable?	O	O	O	O
c)	Is the internet speed fast enough to support use of digital technology during teaching and learning? (e.g., play science videos, animations, simulations during class)	O	O	O	O
d)	The internet is only for the School Management and Administrative staff	O	O	O	O
e)	School provides internet access to support teaching and learning.	O	O	O	O
f)	School provides internet access to learners to support learning.	O	O	O	O

2.3 Availability of the necessary scientific and digital infrastructure to support science education at your school.
scientific infrastructure refers to a collection of science resources needed for science experiments which includes, laboratories, testing facilities, scientific instruments, and equipment.

2.3.1 Is there a laboratory (either physical building or mobile lab) at your school?

Yes	No
O	O

2.3.2 Please rate the availability of each item of laboratory resource or support personnel at your school by selecting the relevant response.

	Never	Seldom	Usually	Always	I don't know	N/A
a) Apparatus for science experiments	O	O	O	O	O	O
b) Chemicals for science experiments	O	O	O	O	O	O
c) Protective clothing for science experiments	O	O	O	O	O	O
d) Lab safety resources (e.g., fire extinguishers)	O	O	O	O	O	O
e) Suitable laboratory assistant(s)	O	O	O	O	O	O

2.3.3 Please indicate the availability of each of the listed below digital resources at your school by selecting the relevant response

	Yes	No	I don't know
a) School has computers/laptops for teacher use	O	O	O
b) School has projectors for lesson delivery	O	O	O

c)	Learners share computers	O	O	O
d)	Each learner is allocated her/his own desktop computer	O	O	O
e)	Each learner has/is allocated her/his own laptop/tablet	O	O	O
f)	Each learner has a smart phone used for digital learning	O	O	O

Section C: The extent to which science teachers are aware of the use of virtual labs in supporting science education.

3.1 What is your level of confidence in using technology in science classes?

Very low	Low	Medium	High	Very High
O	O	O	O	O

Virtual laboratories also known as virtual labs (VL) are web-based simulations (computer-based learning activities, e.g., PHeT Interactive Simulations, Labster, etc.) of real scientific processes and systems which are used to enhance science teaching and learning. Thus, virtual labs allow teachers and learners to virtually interact with an experimental apparatus and do science experiments online and also to explore science concepts in a 3-dimensional form via a digital device e.g., computer/tablet/smart phone. A perfect substitute for a physical lab to do experiments.

3.2 Have you ever heard of the term virtual labs?

Yes	No
O	O

3.3 Do you know where you can access virtual lab teaching and learning resources/materials?

Yes	No	N/A
O	O	O

3.4 Do you have access to virtual lab material?

Yes	No	N/A

O O O

Extent of use of virtual labs (VL) in science education by the teacher

3.5 How often do these activities happen in your science class? Please show by selecting one response per statement.

		Never	Seldom	Usually	Always	N/A
a)	I use science videos to explain concepts	O	O	O	O	O
b)	I use science videos to demonstrate experiments	O	O	O	O	O
c)	I use animations to explain concepts	O	O	O	O	O
d)	I use animations to demonstrate experiments	O	O	O	O	O
e)	I use simulations to explain concepts	O	O	O	O	O
f)	I use simulations to do experiments	O	O	O	O	O
g)	I use head mounted display (HMD) immersive virtual lab to explain concepts	O	O	O	O	O
h)	I use head mounted display (HMD) immersive virtual lab to do experiments	O	O	O	O	O

Extent of learner engagement in digital learning through virtual labs

3.6 What access do the learners in your science class have to digital devices (e.g., computers, tablets, smart phones)? Select one response for each statement.

	Yes	No	Not Sure
a) Each learner has a digital device	O	O	O
b) The class has digital devices that students can share	O	O	O
c) The school has digital devices that the class can use sometimes	O	O	O

3.7 How often do you and your learners do the following activities on digital devices (computers, laptops, tablets, or smart phones) during science lessons? Select one responds per statement.

	Never	Seldom	Sometimes	Always	Not Sure
a) Learners engage with science videos to understand science concepts better	O	O	O	O	O
b) Learners engage with science videos to understand science experiments better	O	O	O	O	O
c) Learners engage with animations to understand science concepts better	O	O	O	O	O
d) Learners engage with animations to understand science experiments better	O	O	O	O	O
e) Learners use simulations to understand science concepts better	O	O	O	O	O
f) Learners use simulations to do science experiments	O	O	O	O	O
g) Learners use head mounted display (HMD) immersive virtual lab to interact with science concepts	O	O	O	O	O

		Never	Seldom	Sometimes	Always	Not Sure
h)	Learners use head mounted display (HMD) immersive virtual lab to do science experiments	O	O	O	O	O
i)	Collaboration: Learners work in groups using simulations to explore science concepts and do experiments using a single/one device (e.g., one tablet/computer per group)	O	O	O	O	O
j)	Collaboration: Learners work in groups remotely/online using simulations to explore science concepts and experiments each using his/her own devices (e.g., tablet/computer/smart phone)	O	O	O	O	O

Section D: The value derived from using virtual labs in science education

4.1 Do you use virtual labs (web-based simulations e.g., PHeT Interactive Simulations, Labster, etc.) for teaching and learning in your science class(es)?

Yes	No
O	O

If you answer "No" to question 4.1 above, please tick N/A throughout question 4.2 below.

4.2 Consider the following statement: ‘Ever since my leaners and I started using virtual lab for teaching and learning, I have observed the following: (select one response per statement).’

		Decreased	No noticeable change	Slight improvement	Significant improvement	N/A
a	Level of teacher’s understanding of	O	O	O	O	O

		Decreased	No noticeable change	Slight improvement	Significant improvement	N/A
	science concepts and experiments					
b	Level of learner knowledge retention of science concepts and experiments	O	O	O	O	O
c	Level of learner's understanding of science concepts	O	O	O	O	O
d	Level of learner's understanding of science experiments	O	O	O	O	O
e	Level of learner performance and achievement in the subject	O	O	O	O	O
f)	Level of learner ownership of their own learning (i.e., level of proactiveness in their learning)	O	O	O	O	O
g	Level of learner personalised learning (allows teacher to easily identify each learner's strengths and weakness and offer the needed support accordingly)	O	O	O	O	O

		Decreased	No noticeable change	Slight improvement	Significant improvement	N/A
h	Level of collaboration and teamwork among learners	O	O	O	O	O
i)	Level of learner engagement and participation during classes	O	O	O	O	O
j)	Level of the overall interest of learners in science subject	O	O	O	O	O
k	Level of the overall teaching and learning experience	O	O	O	O	O

Thank you for the time, and effort you have put into completing this questionnaire

APPENDIX B: Participant Information Sheet

Dear Sir / Madam,

Good day, my name is Godwin Nhauro, and I am a master's student in Digital Business at the University of the Witwatersrand (Wits University), Johannesburg. As part of my studies, I have to undertake a research project, and I am conducting research on the use virtual labs (computer – based science simulations/activities) in science education at selected public schools in Gauteng under the supervision of Prof Rene Pellissier. The aim of this research project is to the find out the extent to which science teachers are aware of the use of virtual labs in supporting science education, the extent to which they are using this digital technology, and the value derived from using them.

As part of this project, I would like to invite you to take part in an answering a questionnaire. This activity will involve you answering multiple choice questions via an online form and will take around 8 -15 minutes.

There will be no personal costs to you if you participate in this project, you will not receive any direct benefits from participation but there are no disadvantages or penalties if you do not choose to participate or if you withdraw from the study. You may withdraw at any time or not answer any question if you do not want to. The questionnaire will be completely confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. If you wish to receive a summary of this report, I will be happy to send it to you. The data collected from this research project will be stored in in a password protected computer and will be kept for 10 years. With your permission the data collected from this research project may be used by other researchers in an anonymized format. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za

Yours sincerely,

Godwin Nhauro

Researcher:

Godwin Nhauro

Supervisor:

Prof Rene Pellissier

APPENDIX C: Consent Form (Participant agreement form)

Title of project: The integration of virtual labs into science education in Gauteng

Name of researcher: Godwin Nhauro

I, ……., agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please circle the relevant options below).

I agree that my participation will remain anonymous	YES	NO
I agree that the researcher may use anonymous quotes in his / her research report	YES	NO
I agree that the interview may be audio recorded	YES	NO
I agree that the information I provide may be used anonymously after this project has ended, for academic purposes by other researchers, subject to their own ethics clearance being obtained.	YES	NO

…… (signature)
…… (name of participant)
…… (date)

…… (signature)

…… (name of person seeking consent)

…… (date)