E-Journal of Humanities, Arts and Social Sciences (EHASS)
ISSN – Online 2720-7722 | Print 2821-8949
Volume 7 Issue 9 2026 pp 2856 - 2867
Available online at: https://noyam.org/journals/ehass/
DOI: https://doi.org/10.38159/ehass.20267927

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Final year high school learners' experiences of using Virtual Chemistry Laboratories in learning acid–base concepts in rural South African schools

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ABSTRACT

Practical experimentation plays a critical role in enhancing learners' understanding of Chemistry concepts. However, many rural schools in South Africa lack functional laboratories, limiting learners' opportunities to conduct experiments. This qualitative study explored final-year high school Grade 12 learners' experiences of using Virtual Chemistry Laboratories (VCLs) when learning Acid–Base Concepts in rural secondary schools. The study was located within an interpretive research paradigm and guided by constructivist learning theory and the Technological Pedagogical Content Knowledge framework. Semi-structured interviews were conducted with twelve Grade 12 learners who participated in a Virtual Chemistry Laboratory intervention focusing on Acid–Base reactions. Data were analysed using thematic analysis. The findings revealed that learners had predominantly positive experiences when using VCLs. These experiences included enhanced enjoyment, improved conceptual understanding, increased motivation, flexible learning opportunities, improved engagement, and positive attitudes towards Chemistry. Learners also appreciated the ability to repeat experiments and learn at their own pace. However, some learners reported minor challenges related to internet connectivity and initial unfamiliarity with digital laboratory tools. The study concludes that VCLs can significantly enhance learners' experiences and conceptual understanding of Acid–Base Concepts in resource-constrained schools. It recommends integrating VCLs into Chemistry teaching to complement traditional laboratory instruction in rural contexts.

Keywords: Virtual Chemistry Laboratories, Learner Experiences, Science Education, Rural School

INTRODUCTION

Chemistry education is highly dependent on practical experimentation to enable learners to observe chemical reactions and understand abstract scientific concepts. Laboratory experiments help learners connect theoretical knowledge with real-world applications and promote scientific inquiry. However, many secondary schools in developing countries experience severe shortages of laboratory infrastructure, equipment, and chemicals.[1] In South Africa, the lack of laboratory facilities is particularly

[1] Masresha Woldeamanuel Melaku, Kebede Feyie Endale, and Adem Hamza Sualih, "Practices and Challenges in Implementing Practical Activities in Chemistry Teaching: A Case Study of Secondary Schools in Dire Dawa Administration," *African Journal of Chemical Education* 15, no. 2 (2025): 39–64.

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PUBLICATION HISTORY - Received: 24th March, 2026 | Accepted: 19th August, 2026 | Published: 2nd November, 2026.
TO CITE THIS ARTICLE – Hungwe, Rudorwashe, Mendon Dewa, and Mamothibe Thamae. "Final year high school learners' experiences of using Virtual Chemistry Laboratories in learning acid–base concepts in rural South African schools." *E-Journal of Humanities, Arts and Social Sciences* 7, no.9 (2026): 2856 - 2867. https://doi.org/10.38159/ehass.20267927
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prevalent in rural schools, where learners often rely solely on teacher explanations and textbook illustrations instead of practical experiments.[2] This limitation negatively affects learners' conceptual understanding of complex topics such as Acids and Bases in Chemistry. To address these challenges, digital technologies such as VCLs have been introduced as alternative approaches to practical science instruction. Virtual Laboratories simulate real experiments and allow learners to manipulate chemicals, observe reactions, and analyse results in a safe and interactive environment. Virtual Chemistry Laboratories have the potential to improve learners' conceptual understanding and engagement by allowing them to repeat experiments and visualise chemical processes that may be difficult to observe in traditional laboratories.[3] Despite the growing interest in Virtual Laboratories, there is still limited research exploring learners' experiences of using VCLs, particularly in rural African contexts. Understanding learners' experiences is important because learners' attitudes, engagement, and motivation influence how they interact with technological tools and ultimately shape their learning outcomes. Therefore, this study explores Grade 12 learners' experiences of using VCLs when learning Acid–Base Concepts in rural South African schools. The following research question guided the study: What are the experiences of Grade 12 learners when using Virtual Chemistry Laboratories to learn Acid–Base Concepts?

LITERATURE REVIEW

Learners' experiences when using digital laboratory technologies

Learners' experiences play a crucial role in shaping their engagement and achievement in science education. Their experiences can be understood as events or processes that individuals undergo, and that influence their understanding, attitudes, and skills development. In science education, laboratory experiences provide opportunities for learners to develop experimental skills, explore scientific concepts, and actively participate in the learning process.[4] However, limited resources, time, and safety concerns, particularly in under-resourced contexts such as rural South African schools, often constrain traditional laboratory instruction. Recent studies have highlighted the potential of digital laboratory technologies, particularly Virtual Laboratories, to enhance learners' experiences in science learning.[5]

Virtual Laboratories allow learners to perform experiments repeatedly, manipulate variables, and observe chemical reactions in a controlled digital environment, and these affordances support inquiry-based learning and allow learners to learn from mistakes without safety risks.[6] Furthermore, Virtual Laboratories have been shown to improve conceptual understanding of abstract topics such as Acid–Base Chemistry by enabling visualization of microscopic processes.[7] Research also indicates that Virtual Laboratories increase learner motivation and engagement, provide immediate feedback and promote self-directed learning, which enhances learners' sense of autonomy and competence.[8] In addition, learners often report positive attitudes towards the use of digital tools because of their interactive and immersive nature. However, some studies have reported challenges associated with Virtual Laboratories, including technological limitations, lack of digital literacy skills, and limited access to reliable internet connectivity.[9] These constraints may negatively influence learners'

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[2] Lindokuhle Soyikwa and Sakyiwaa Boateng, "Teaching Physical Sciences in South African Rural High Schools: Learner and Teacher Views about the Challenges," *Issues in Educational Research* 34, no. 4 (2024): 1573–95.

[3] Vysakh Kani Kolil and Krishnashree Achuthan, "Virtual Labs in Chemistry Education: A Novel Approach for Increasing Student's Laboratory Educational Consciousness and Skills," *Education and Information Technologies* 29, no. 18 (2024): 25307–31.

[4] Preeti Kumari, Adrian Mwesigye, and Sudi Balimuttajjo, "Science Laboratory Education and Students' Perceived Behavior towards Science Education: A Review,"*Journal of Research Innovation and Implications in Education* 8, no.4 (2024): 555–61.

[5] Ronald L Reyes et al., "Enhancing Experiential Science Learning with Virtual Labs: A Narrative Account of Merits, Challenges, and Implementation Strategies," *Journal of Computer Assisted Learning* 40, no. 6 (2024): 3167–86.

[6] Hiwot Bazie et al., "The Effect of Virtual Laboratories on the Academic Achievement of Undergraduate Chemistry Students: Quasi-Experimental Study," *JMIR Formative Research* 8, no. 1 (2024): e64476.

[7] Tadesse, Hagos Nigussie. "The role of virtual laboratories in advancing student learning on acid–base equilibrium." *Chemistry Teacher International* 0 (2025).

[8] M. Al-Hitani and F Embarak, "Cultivating Independent Learners: Designing an Innovative Interactive Model to Enhance Self-Directed Learning and Autonomy in Elementary Education," *International Journal of Innovative Research in Science, Engineering and Technology. Https://Doi. Org/10.15680/IJIRSET*, 2025.

[9] Ahmed Jamah Alnagrat Alnagrat, Rizalafande Che Ismail, and Syed Zulkarnain Syed Idrus, "The Opportunities and Challenges in Virtual Reality for Virtual Laboratories," *Innovative Teaching and Learning Journal* 6, no. 2 (2022): 73–89; Fitsum G Deriba,

experiences, particularly in rural and under-resourced schools. Despite these challenges, Virtual Laboratories remain promising tools for improving science education where traditional laboratory infrastructure is inadequate.

Digital laboratory technologies and learner achievement in Chemistry

Beyond influencing learner experiences, digital laboratory technologies have been widely associated with improvements in academic achievement in Chemistry. Empirical studies suggest that learners who engage with Virtual Laboratories often demonstrate higher levels of conceptual understanding and improved performance on assessments compared to those exposed to traditional teaching methods alone.[10] Virtual Laboratories are particularly effective in supporting the learning of complex and abstract Chemistry concepts such as Acid–Base reactions, chemical equilibrium, and molecular interactions. These concepts often require visualisation at the submicroscopic level, which is difficult to achieve through conventional instruction. Simulations enable learners to connect macroscopic observations with symbolic and particulate representations, thereby improving conceptual coherence.[11] Moreover, blended approaches that combine virtual and physical laboratories have been shown to produce even stronger learning gains. Such approaches leverage the strengths of both environments, hands-on skills from physical laboratories and conceptual visualisation from Virtual Laboratories. This is particularly relevant in contexts where access to fully equipped laboratories is limited. However, factors such as instructional design, teacher competence, and the alignment of technology with curriculum goals influence the impact of digital laboratories on achievement. Studies emphasise that technology alone does not guarantee improved outcomes; instead, it must be effectively integrated into pedagogy to support meaningful learning.[12]

Integration of Virtual Chemistry Laboratories in under-resourced contexts

The integration of VCLs in under-resourced contexts has gained increasing attention in recent literature because of their potential to enhance teaching and learning of complex topics such as Acids and Bases in secondary education. The literature highlights that VCLs can enhance conceptual understanding, learner engagement, and access to practical experiences, particularly in under-resourced rural school contexts.[13] Studies further demonstrate how learners' experiences with these technologies influence their attitudes, motivation, and academic achievement in Chemistry. However, limited research has specifically examined Grade 12 learners' lived experiences of using VCLs for Acid–Base Concepts in rural South African schools, thereby necessitating further scholarly attention. In many developing regions, including rural areas of South Africa, schools face significant challenges such as inadequate laboratory infrastructure, shortage of chemicals and equipment, and overcrowded classrooms.[14] These challenges limit opportunities for practical experimentation, which is essential for effective science learning. Virtual Laboratories provide a viable alternative by offering cost-effective and scalable solutions that can be accessed through computers or mobile devices.

Studies have shown that VCLs can bridge the gap between theory and practice by allowing learners to engage in simulated experiments even in the absence of physical laboratories.[15] Additionally, mobile-compatible Virtual Laboratories have expanded access in contexts where smartphones are more readily available than traditional computers. However, the successful integration of VCLs in such

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Mohammed Saqr, and Markku Tukiainen, "Exploring Barriers and Challenges to Accessibility in Virtual Laboratories: A Preliminary Review," in *Proceedings of the Technology-Enhanced Learning in Laboratories CEUR Workshop (TELL 2023)*, vol. 27, 2023.

[10] Céline Byukusenge, Florien Nsanganwimana, and Albert Paulo Tarmo, "Investigating the Effect of Virtual Laboratories on Students' Academic Performance and Attitudes towards Learning Biology," *Education and Information Technologies* 29, no.1 (2024): 1147–71.

[11] Bokai Hu, Liying Zhu, and Hualin Bi, "Effect of Computer Simulations on Student Ability to Translate Chemical Representations When Learning the Particulate Nature of Matter Concept," *Journal of Chemical Education* 101, no. 10 (2024): 4149–60.

[12] Mark Ching-Pong Poo, Yui-yip Lau, and Qiong Chen, "Are Virtual Laboratories and Remote Laboratories Enhancing the Quality of Sustainability Education?," *Education Sciences* 13, no. 11 (2023): 1110.

[13] Tadesse Hagos, "The Effects of Laboratory Resources, Student Engagement, and Teacher Quality on Chemistry Achievement," *African Journal of Chemical Education AJCE*, 2026, 21.

[14] Dumsani Mncube, "Analysis of the Impact of Poor Infrastructure Provision on the Quality of Education in Rural Schools," *Axiom Academic Publishers* 1, no. ISBN: 978-1-991239-18-1 (2023): 71–98.

[15] Nitin Rauta et al., "Enhancing Chemical Engineering Education: The Role of Virtual Labs in Bridging Theory and Practice," *Jurnal Kejuruteraan* 38, no. 1 (2026): 25–33.

contexts requires addressing several key challenges, including teacher training, infrastructure development, and curriculum alignment. Furthermore, policy support and investment in digital infrastructure are critical to ensuring equitable access to technology-enhanced learning. Despite these challenges, the literature suggests that VCLs have significant potential to transform science education in under-resourced settings by enhancing learner experiences, improving academic achievement, and promoting equitable access to quality education.[16]

THEORETICAL FRAMEWORK

This study is guided by Constructivist Learning Theory and the Technological Pedagogical Content Knowledge (TPACK) framework, which together provide a robust lens for understanding the integration of VCLs in teaching and learning. Constructivist learning theory posits that learners actively construct knowledge through interaction with their learning environment.[17] Learning occurs when learners engage in inquiry, experimentation, and problem-solving rather than passively receiving information. Virtual Laboratories support constructivist learning by providing interactive environments where learners manipulate variables, test hypotheses, and observe outcomes in real time. This aligns with learner-centred pedagogies that emphasise active engagement and knowledge construction. The TPACK framework emphasises integrating technology, pedagogy, and content knowledge for effective teaching. According to this framework, teachers must develop an understanding of how to integrate appropriate technologies with instructional strategies and subject content to enhance learning outcomes.[18]

Recent literature highlights the growing significance of digital laboratory technologies, particularly VCLs, in enhancing learners' experiences in science education. Learners' experiences are central to shaping their engagement, attitudes, and conceptual understanding, especially in subjects like Chemistry that involve abstract concepts.[19] Studies indicate that VCLs provide interactive environments where learners can manipulate variables, repeat experiments, and visualise microscopic processes that are otherwise difficult to observe in traditional laboratories.[20] These features promote active participation and inquiry-based learning, which are key principles of effective science instruction. Furthermore, digital simulations have been found to increase learner motivation and autonomy by providing immediate feedback and opportunities for self-paced learning.[21]

In addition to improving learner experiences, digital laboratory technologies have been associated with enhanced academic achievement in Chemistry. Empirical studies show that learners who use Virtual Laboratories often demonstrate improved conceptual understanding and better performance in assessments compared to those exposed to traditional methods alone.[22] This is particularly relevant for complex topics such as Acid–Base Chemistry, where visualisation of submicroscopic processes supports deeper understanding. However, the effectiveness of VCLs depends on factors such as instructional design, teacher competence, and access to technological resources. In under-resourced contexts, limited infrastructure, inadequate digital skills, and poor internet connectivity may hinder effective implementation.[23] Despite these constraints, VCLs remain a viable alternative for supporting practical science learning where traditional laboratories are unavailable.

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[16] Blessing Nemadziva, Catherine Cole, and Steven Sexton, "Using Science Communication Strategies to Close the Resource Gap in Under-Resourced Schools: A Design-Based Study Focusing on Rural Schools in South Africa," *Research in Science Education* 55, no. 6 (December 20, 2025): 1643–63, https://doi.org/10.1007/s11165-025-10243-3.

[17] L Vygotsky, "Social Constructivism," *Mind in Society*, 1978.

[18] Punya Mishra and Matthew J Koehler, "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge," *Teachers College Record* 108, no. 6 (2006): 1017–54.

[19] Tadesse Hagos, "Progressivism in Chemistry Education: Emphasizing Student-Centered Learning and Real-World Relevance," *African J. Chem. Educ* 15, no. 1 (2025): 147–79.

[20] Kolil and Achuthan, "Virtual Labs in Chemistry Education: A Novel Approach for Increasing Student's Laboratory Educational Consciousness and Skills."

[21] Hiwot Bazie Bewota et al., "Perceptions and Challenges in Digital Chemistry Instruction: Student and Instructor Experiences with Virtual Laboratories," *EURASIA Journal of Mathematics, Science and Technology Education* 22, no. 1 (2026): em2756.

[22] Nikolaos Papalazarou, Ioannis Lefkos, and Nikolaos Fachantidis, "The Effect of Physical and Virtual Inquiry-Based Experiments on Students' Attitudes and Learning," *Journal of Science Education and Technology* 33, no. 3 (2024): 349–64.

[23] C T Orji and J Perumal, "Development Needs Analysis of Digital Technology in Stem Education: Insights from Rural and under-Resourced Schools," in *INTED2025 Proceedings* (IATED, 2025), 7494–7502.

The Constructivist Learning Theory and the TPACK framework underpin the integration of VCLs in teaching and learning. Constructivism emphasises that learners actively construct knowledge through interaction, inquiry, and experimentation, which aligns with the interactive nature of Virtual Laboratories. The TPACK framework also highlights the importance of integrating technology with pedagogy and content knowledge to enhance learning outcomes. Together, these frameworks provide a comprehensive foundation for understanding how VCLs can be effectively implemented to promote learner engagement, conceptual understanding, and achievement, particularly in resource-constrained educational environments.

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METHODOLOGY

Research Design

The study was conducted within the interpretive research paradigm. The interpretive paradigm assumes that reality is socially constructed and that individuals develop meanings based on their experiences and interactions with their environment. Within this paradigm, the researchers sought to understand how learners interpreted their experiences of using VCLs during Chemistry lessons. The study used an exploratory research design. Exploratory research designs are appropriate when a phenomenon has not been extensively studied within a specific context. In the case of this study, limited research has examined learners' experiences of using VCLs in rural South African schools. The exploratory design therefore allowed the researchers to gain deeper insights into how learners perceived and experienced the use of virtual laboratory simulations when learning Acid–Base Concepts.

Research strategy and sampling

Due to the nature of the phenomenon explored in this study, a qualitative research approach was adopted. Qualitative research approaches are appropriate for studies that seek to explore participants' experiences, perceptions, and behaviours within specific contexts.[24] In this study, the qualitative approach enabled the researchers to explore Grade 12 learners' experiences when using VCLs in learning Acid–Base Concepts in rural secondary schools. Two rural secondary schools offering Grade 12 Physical Sciences were purposively selected for the study. These schools were selected because they had limited access to physical laboratory facilities and therefore provided a suitable context to explore the use of VCLs as an alternative practical learning tool.

Data Collection and Analysis

The study followed established ethical research principles. Approval for the study was obtained from the Durban University of Technology Institutional Research Ethics Committee (IREC) under Ethics Clearance Number IREC 043/25**.** Subsequently, the Head of Department of the Limpopo Department of Education granted permission to conduct the study. This was followed by gatekeeper permission from the principals of the two participating rural secondary schools. Because the participants were Grade 12 learners, written informed consent was obtained from their parents or legal guardians, while written assent was obtained from the learners themselves before participation. Participants were informed that their participation was voluntary and that they were free to withdraw from the study at any stage without penalty. To ensure confidentiality and anonymity, pseudonyms were assigned to all participants, and all interview recordings and transcripts were stored securely and accessed only by the research team.

Semi-structured interviews were conducted with twelve Grade 12 learners who participated in the VCL intervention on Acid–Base Concepts. Semi-structured interviews were selected because they allow participants to describe their experiences in depth while allowing the researchers to probe emerging issues for clarification. This approach was appropriate for exploring learners' perceptions, attitudes, and experiences regarding the use of VCLs in Chemistry learning. Participants were selected using purposive maximum variation sampling to ensure representation of different academic achievement levels and both genders. Six learners were selected from each of the two participating schools, making a total sample of twelve participants. Each school contributed three male and three

[24] Josephine Oranga and Audrey Matere, "Qualitative Research: Essence, Types and Advantages," *Open Access Library Journal* 10, no. 12 (2023): 1–9.

female learners, giving an overall sample of six males and six females. Participant selection was guided by learners' performance in the post-intervention Chemistry Achievement Test (CAT). From each school, six learners were selected to represent three achievement categories: two high-achieving learners (one male and one female), two average-achieving learners (one male and one female), and two low-achieving learners (one male and one female)**.** This sampling strategy ensured that diverse learner experiences and perspectives regarding the use of VCLs were captured.

The interviews were conducted after the VCL intervention to allow participants sufficient time to reflect on their learning experiences. Each interview lasted between 20 and 30 minutes and was conducted in a quiet room on the school premises to provide a comfortable and distraction-free environment. With the permission of the participants, all interviews were recorded on audio to ensure an accurate record of their responses. The audio recordings were transcribed verbatim to preserve participants' original views and expressions. The researchers repeatedly read the transcripts to familiarise themselves with the data before commencing the coding process. The interview data were analysed using thematic analysi**s**. Initially, open coding was conducted to identify meaningful statements relating to learners' experiences of using the Virtual Chemistry Laboratories. Similar codes were then grouped into categories, after which the categories were refined into broader themes to represent recurring patterns in the responses of participants. Through this iterative analytical process, two major themes emerged, reflecting learners' experiences, perceived learning benefits, and challenges associated with using VCLs to learn Acid–Base Concepts.

Credibility was strengthened through prolonged engagement with the data, repeated reading of interview transcripts, and the use of verbatim quotations to support the interpretation of findings. The reliability was enhanced by maintaining a clear audit trail documenting the coding process, theme development, and analytical decisions. Confirmability was promoted by ensuring that interpretations were grounded in participants' own words and by maintaining researcher reflexivity throughout the analysis. Transferability was supported by providing detailed descriptions of the research context, participant selection procedures, and data collection process, thereby enabling readers to determine the applicability of the findings to similar educational contexts.

PRESENTATION OF FINDINGS

Thematic Analysis

The qualitative data generated from learners' interview responses were analysed thematically to identify recurring patterns in their experiences and perceptions regarding the use of VCLs. Through this process, two overarching themes emerged, each capturing a distinct dimension of learners' engagement with VCLs in the context of Acid–Base Chemistry. These themes reflect both the experiential aspects of interacting with Virtual Laboratories and the perceived academic and affective benefits derived from their use. Within each theme, specific subthemes were identified to provide a more nuanced understanding of learners' viewpoints. The two main themes and their corresponding subthemes are summarised in Table 1.

Table 1: Themes and subthemes emerging from learners' interview responses

Theme	Subthemes
Experiences associated with the use of Virtual Chemistry Laboratories	Positive learning experiences using VCLs
	Challenges experienced when using VCLs
Perceived learning benefits of Virtual Chemistry Laboratories	Improved conceptual understanding of Acid–Base concepts
	Increased motivation and positive attitudes toward Chemistry

Table 1 presents two overarching themes derived from learners' interview responses, highlighting both their experiences with VCLs and the perceived learning benefits. The first theme, *experiences associated with the use of VCLs*, shows that learners reported generally positive learning

experiences, such as increased engagement and ease of conducting experiments. However, this theme also captures some challenges, including technical difficulties and limited access to devices or internet connectivity. The second theme, *perceived learning benefits of VCLs*, indicates that learners believed the use of Virtual Laboratories enhanced their conceptual understanding of Acid–Base Concepts. Additionally, learners reported increased motivation and more positive attitudes toward Chemistry, suggesting that VCLs not only support cognitive gains but also improve affective outcomes in learning.

Experiences associated with the use of Virtual Chemistry Laboratories

This theme reports on the Grade 12 learners' experiences when using VCLs during the learning of Acid–Base Concepts. The findings indicate that learners had largely positive experiences with the technology. However, some challenges have also been reported. The reflections of the learners are presented in the subthemes below.

Positive learning experiences using Virtual Chemistry Laboratories

Learners reported predominantly positive experiences when using VCLs, particularly in terms of engagement, enjoyment, and the ability to visualise abstract chemical processes. Several learners described the simulations as more stimulating than traditional classroom instruction. One learner expressed enthusiasm for the visual representation of chemical reactions:

"Using the virtual laboratory made the lesson interesting because we could see the reactions happening on the screen." (SAS3)

"I enjoyed repeating the experiment several times until I understood how the titration works."(SBS2)

These responses indicate that VCLs created engaging learning environments that captured learners' interest and promoted active participation. In addition, learners highlighted the role of VCLs in supporting procedural understanding and step-by-step learning. One learner explained:

"The virtual experiment helped me understand titration better because I could follow each step and see the colour change clearly." (SAS2)

This indicates that structured simulations enabled learners to follow experimental procedures more effectively. The ability to observe colour changes during titration enhanced understanding of key concepts such as the endpoint of a reaction. Furthermore, learners reported that the flexibility of the virtual environment supported self-paced learning:

"It was easier to follow the experiment because everything was shown step by step and I could pause and go back if I didn't understand something." (SBS6)

"The good thing about the virtual lab is that you can repeat the experiment many times until you understand what is happening." (SAS6)

"The good thing about the virtual lab is that I could repeat the experiment until I understood the steps."(SAS1)

These responses demonstrate that VCLs promote autonomy by allowing learners to revisit and repeat experiments, reinforcing understanding. Additionally, learners reported greater motivation when using VCLs:

"The virtual experiments made me want to learn more about Chemistry because I could see how the reactions happen."(SAS5)

This suggests that the interactive nature of the simulations stimulated curiosity and encouraged active engagement in learning.

Challenges experienced when using Virtual Chemistry Laboratories

Despite the positive experiences reported, learners also identified several challenges associated with the use of VCLs. One of the main challenges related to technological infrastructure, particularly internet connectivity. For example, one learner stated:

"Sometimes the internet connection was slow, which made it difficult to load the experiment quickly." (SBS2)

This response highlights the importance of reliable technological infrastructure for the effective implementation of digital learning tools. In contexts where connectivity is unstable, learners may experience delays that disrupt the learning process. Another challenge reported was the initial difficulty in using the virtual laboratory interface. One learner noted:

"At first it was confusing because I had never used a virtual lab before, but after some time I became used to it." (SBS5)

This suggests that unfamiliarity with digital platforms may hinder initial engagement. However, the statement also indicates that learners can adapt over time as they become more familiar with the technology. These findings imply that orientation and technical support are necessary to facilitate effective use of VCLs.

Perceived Learning Benefits of Virtual Chemistry Laboratories

The two key sub-themes that emerged from the study are improved conceptual understanding of Acid–Base Concepts and increased motivation and positive attitudes toward Chemistry.

Improved conceptual understanding of Acid–Base Concepts

Learners reported several learning benefits associated with the use of VCLs, particularly improved conceptual understanding and enhanced motivation toward Chemistry. Many learners indicated that the simulations helped them understand Acid–Base Concepts more clearly. For instance, one learner explained:

"Before using the virtual lab, I did not understand titration, but now I can see how the acid and base react."(SAS6)

Similarly, other learners highlighted how visualisation supported their understanding:

"The virtual lab helped me understand how acids and bases react because I could actually see what happens during the experiment." (SAS3)

"Before using the virtual lab, titration was difficult for me to understand, but when I saw the colour change in the simulation, it became clearer." (SBS6)

These responses suggest that VCLs enhance conceptual understanding by making abstract processes visible. Furthermore, learners emphasised the role of Virtual Laboratories in linking theory to practice:

"When the teacher explained the theory before, it was difficult to imagine, but when we did the virtual experiment, it made sense." (SAS1)

Increased motivation and positive attitudes toward Chemistry

Another noticeable outcome from thematic analysis of responses from Grade 12 learners is the shift in learners' motivation and attitudes toward Chemistry, particularly when effective teaching strategies, contextualised content, and engaging VCLs learning environments are implemented. This indicates that VCLs can bridge the gap between theoretical instruction and practical application. In addition to conceptual understanding, learners reported increased motivation and more positive attitudes toward Chemistry. For example, one learner commented:

"Using the virtual lab made Chemistry more interesting for me because it felt like doing a real experiment." (SAS4)

Similarly, another learner stated:

"I enjoyed the virtual experiments because they made the lesson more interactive and exciting." (SBS3)

A shift in learners' perceptions of Chemistry was also evident:

"Before this, I thought Chemistry was difficult, but after using the virtual lab, I realised that it can be easier to understand." (SAS2)

DISCUSSION

The results and findings of this study present insights into learners' experiences and perceptions regarding the use of VCLs in the learning of Acid–Base Chemistry. Drawing on qualitative data from

learner interviews, the analysis reveals how VCLs influence both the learning process and learners' attitudes toward Chemistry. The findings highlight not only the nature of learners' interactions with virtual laboratory environments but also the educational value they attach to these tools. The findings indicate that learners' experiences with VCLs were largely positive, although a few challenges related to technological accessibility and initial unfamiliarity with the platform were reported.

Learners derived satisfaction in particular from experiences such as visualising chemical reactions, repeating experiments, and learning at their own pace through interactive simulations. The excerpt from Learner SAS3, *"The virtual lab helped me understand how acids and bases react because I could actually see what happens during the experiment,"* reveals the importance of visual and experiential learning environments in science education. This aligns with the constructivist learning theory, which emphasises that learners construct knowledge through active engagement and interaction with learning materials rather than through passive reception of information.[25] Learning occurs when learners interact with their environment and actively build understanding based on prior knowledge and new experiences. In this study, VCLs appeared to provide such interactive environments where learners could manipulate variables and observe simulated reactions, thereby enhancing their conceptual understanding of Acid–Base Chemistry.

The findings are also consistent with research conducted within the field of Science Education, which shows that digital simulations can enhance learners' engagement and comprehension of abstract scientific concepts.[26] In traditional classroom settings, many chemical processes occur at microscopic levels that are difficult to visualise. The use of virtual simulations enables learners to observe these processes more clearly, thereby bridging the gap between theoretical explanations and practical experimentation. Furthermore, learners reported that the ability to repeat experiments and learn at their own pace improved their learning experiences. For example, Learner SAS6 stated, *"The good thing about the virtual lab is that you can repeat the experiment many times until you understand what is happening."* This finding highlights one of the key advantages of Virtual Laboratories compared to traditional laboratories, where time constraints and limited resources may restrict the number of experiments learners can perform.

The opportunity to repeat experiments aligns with the core ideas of constructivist learning, where learners refine their understanding through iterative exploration and reflection. By repeatedly interacting with the simulations, learners were able to consolidate their understanding of the chemical processes involved in Acid–Base reactions. Another important finding of the study was the increased motivation and engagement among learners when using VCLs. Learners described the simulations as interactive and enjoyable, suggesting that technology-enhanced learning environments can positively influence learners' attitudes toward Chemistry. For example, Learner SBS4 commented that *"Using the virtual lab made Chemistry more interesting for me because it felt like doing a real experiment."* This suggests that the virtual simulations helped create an immersive learning experience that stimulated learners' curiosity and interest in the subject.

These findings resonate with studies that have demonstrated the motivational potential of technology integration in science education. Interactive simulations allow learners to explore scientific phenomena in ways that traditional instruction may not easily facilitate. Consequently, technology-based learning environments can increase learners' participation and engagement in classroom activities. From the perspective of the TPACK framework, the effective integration of VCLs demonstrates the interplay between technology, pedagogy, and content knowledge in enhancing teaching and learning.[27] In this study, the virtual laboratory simulations served as technological tools that supported the teaching of complex Chemistry concepts such as Acid–Base reactions. When combined with appropriate pedagogical strategies, these tools can facilitate deeper conceptual understanding among learners.

However, despite the largely positive experiences reported by learners, the study also revealed some challenges associated with using VCLs. For instance, Learner SAS3 indicated that slow internet

[25] Vygotsky, "Social Constructivism."
[26] Bewota et al., "Perceptions and Challenges in Digital Chemistry Instruction: Student and Instructor Experiences with Virtual Laboratories."
[27] Mishra and Koehler, "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge."

connectivity sometimes affected the loading of the simulations. This highlights the broader infrastructural challenges that many rural schools face when implementing digital learning technologies. Limited technological infrastructure can constrain the effective integration of digital tools in teaching and learning. In rural schools, unreliable internet connectivity and limited access to digital devices may hinder the widespread adoption of Virtual Laboratories. Therefore, while VCLs offer promising opportunities to enhance science education, their successful implementation depends on the availability of adequate technological infrastructure.

Another challenge learners reported was initial unfamiliarity with the virtual laboratory interface. For example, Learner SBS5 explained that the simulations were confusing at first because they had never used such tools before. This finding suggests that learners may require orientation and guidance when first introduced to digital laboratory environments. Despite these challenges, learners' experiences improved as they became more familiar with the platform. This indicates that with proper training and continued exposure, learners can effectively use virtual laboratory tools to support their learning. Overall, the findings of this study demonstrate that VCLs have the potential to enhance learners' experiences and conceptual understanding of Acid–Base concepts.[28] By providing interactive simulations that allow learners to visualise reactions and repeat experiments, VCLs create learning environments that align with constructivist principles and support integrating technology within the TPACK framework.

Overall, the results indicate that VCLs play a significant role in enhancing learners' conceptual understanding while simultaneously fostering positive attitudes and motivation toward Chemistry. At the same time, the findings acknowledge challenges that can affect the effective implementation of VCLs, particularly in resource-constrained rural school contexts. These insights provide a balanced understanding of both the opportunities and limitations associated with integrating Virtual Laboratories into Chemistry education. These findings suggest that VCLs not only improve understanding but also positively influence learners' attitudes, making Chemistry more accessible and engaging.

RECOMMENDATIONS

Based on the findings of this study, it is recommended that VCLs be integrated into the teaching of Chemistry as complementary instructional tools, particularly in rural and under-resourced schools where access to physical laboratory facilities is limited. The use of VCLs can enhance learners' conceptual understanding, engagement, motivation, and opportunities for repeated practical experimentation. Teacher education institutions, school management teams, and education authorities should provide continuous professional development programmes that equip Physical Sciences teachers with the technological, pedagogical, and content knowledge required for the effective integration of VCLs into classroom practice. This training should include the pedagogical use of digital simulations, learner support strategies, and classroom implementation techniques. The Department of Basic Education (DBE) and Provincial Departments of Education (PDE) should prioritise investment in reliable digital infrastructure, including internet connectivity, computers, tablets, and technical support, particularly in rural schools. Strengthening digital infrastructure will facilitate the successful implementation and sustainability of VCLs and improve equitable access to quality practical science education. Future research should extend this work by including teachers' experiences, classroom observations, and schools from different geographical contexts. Employing multiple qualitative data collection methods and larger samples would further strengthen understanding of the long-term effectiveness and scalability of VCLs in Chemistry education.

CONCLUSION

This study explored Grade 12 learners' experiences of using VCLs to learn Acid–Base Concepts in rural South African schools. The findings demonstrate that learners generally had positive experiences with VCLs, particularly regarding increased engagement, improved conceptual understanding, enhanced motivation, and opportunities to learn at their own pace through repeated experimentation. The

[28] Hagos Nigussie Tadesse, "The Role of Virtual Laboratories in Advancing Student Learning on Acid–Base Equilibrium," *Chemistry Teacher International* 8, no. 1 (2026): 109–28.

interactive nature of the simulations enabled learners to visualise abstract chemical processes and helped bridge the gap between theoretical instruction and practical experimentation. Although learners reported overwhelmingly positive experiences, the study also identified challenges that may influence the effective implementation of VCLs, including unreliable internet connectivity and learners' initial unfamiliarity with digital laboratory environments. These findings suggest that successful implementation of VCLs requires adequate technological infrastructure, learner orientation, and ongoing instructional support. This study has several limitations. First, qualitative data were collected using only semi-structured interviews. Future studies could strengthen methodological triangulation by incorporating classroom observations, learner reflective journals, and focus group discussions. Second, the study focused exclusively on learners' experiences. Future research should include teachers' perspectives to provide a more comprehensive understanding of VCL implementation. Finally, the study was carried out in only two rural secondary schools; therefore, future research involving larger samples and diverse educational contexts would improve the transferability of the findings.

BIBLIOGRAPHY

Al-Hitani, M., and F. Embarak. "Cultivating Independent Learners: Designing an Innovative Interactive Model to Enhance Self-Directed Learning and Autonomy in Elementary Education." *International Journal of Innovative Research in Science, Engineering and Technology. Https://Doi. Org/10.15680/IJIRSET*, 2025.

Alnagrat, Ahmed Jamah Alnagrat, Rizalafande Che Ismail, and Syed Zulkarnain Syed Idrus. "The Opportunities and Challenges in Virtual Reality for Virtual Laboratories." *Innovative Teaching and Learning Journal* 6, no. 2 (2022): 73–89.

Bazie, Hiwot, Bekele Lemma, Anteneh Workneh, and Ashebir Estifanos. "The Effect of Virtual Laboratories on the Academic Achievement of Undergraduate Chemistry Students: Quasi-Experimental Study." *JMIR Formative Research* 8, no. 1 (2024): e64476.

Bewota, Hiwot Bazie, Bekele Lemma, Anteneh Wasyhun, and Ashebir Bezabih. "Perceptions and Challenges in Digital Chemistry Instruction: Student and Instructor Experiences with Virtual Laboratories." *EURASIA Journal of Mathematics, Science and Technology Education* 22, no. 1 (2026): em2756.

Byukusenge, Céline, Florien Nsanganwimana, and Albert Paulo Tarmo. "Investigating the Effect of Virtual Laboratories on Students' Academic Performance and Attitudes towards Learning Biology." *Education and Information Technologies* 29, no. 1 (2024): 1147–71.

Deriba, Fitsum G, Mohammed Saqr, and Markku Tukiainen. "Exploring Barriers and Challenges to Accessibility in Virtual Laboratories: A Preliminary Review." In *Proceedings of the Technology-Enhanced Learning in Laboratories CEUR Workshop (TELL 2023)*, Vol. 27, 2023.

Hagos, Tadesse. "Progressivism in Chemistry Education: Emphasizing Student-Centered Learning and Real-World Relevance." *African J. Chem. Educ* 15, no. 1 (2025): 147–79.

———. "The Effects Of Laboratory Resources, Student Engagement, and Teacher Quality on Chemistry Achievement." *African Journal of Chemical Education AJCE*, 2026, 21.

Hu, Bokai, Liying Zhu, and Hualin Bi. "Effect of Computer Simulations on Student Ability to Translate Chemical Representations When Learning the Particulate Nature of Matter Concept." *Journal of Chemical Education* 101, no. 10 (2024): 4149–60.

Kolil, Vysakh Kani, and Krishnashree Achuthan. "Virtual Labs in Chemistry Education: A Novel Approach for Increasing Students' Laboratory Educational Consciousness and Skills." *Education and Information Technologies* 29, no. 18 (2024): 25307–31.

Kumari, Preeti, Adrian Mwesigye, and Sudi Balimuttajjo. "Science Laboratory Education and Students' Perceived Behavior towards Science Education: A Review." *Journal of Research Innovation and Implications in Education* 8, no. 4 (2024): 555–61.

Melaku, Masresha Woldeamanuel, Kebede Feyie Endale, and Adem Hamza Sualih. "Practices and Challenges in Implementing Practical Activities in Chemistry Teaching: A Case Study of Secondary Schools in Dire Dawa Administration." *African Journal of Chemical Education* 15, no. 2 (2025): 39–64.

Mishra, Punya, and Matthew J. Koehler. "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge." *Teachers College Record* 108, no. 6 (2006): 1017–54.

Mncube, Dumsani. "Analysis of the Impact of Poor Infrastructure Provision on the Quality of Education in Rural Schools." *Axiom Academic Publishers* 1, no. ISBN: 978-1-991239-18-1 (2023): 71–98.

Nemadziva, Blessing, Catherine Cole, and Steven Sexton. "Using Science Communication Strategies to Close the Resource Gap in Under-Resourced Schools: A Design-Based Study Focusing on Rural Schools in South Africa." *Research in Science Education* 55, no. 6 (December 20, 2025): 1643–63. https://doi.org/10.1007/s11165-025-10243-3.

Oranga, Josephine, and Audrey Matere. "Qualitative Research: Essence, Types and Advantages." *Open Access Library Journal* 10, no. 12 (2023): 1–9.

Orji, C T, and J Perumal. "Development Needs Analysis of Digital Technology in Stem Education: Insights from Rural and under-Resourced Schools." In *INTED2025 Proceedings*, 7494–7502. IATED, 2025.

Papalazarou, Nikolaos, Ioannis Lefkos, and Nikolaos Fachantidis. "The Effect of Physical and Virtual Inquiry-Based Experiments on Students' Attitudes and Learning." *Journal of Science Education and Technology* 33, no. 3 (2024): 349–64.

Poo, Mark Ching-Pong, Yui-yip Lau, and Qiong Chen. "Are Virtual Laboratories and Remote Laboratories Enhancing the Quality of Sustainability Education?" *Education Sciences* 13, no. 11 (2023): 1110.

Rauta, Nitin, Wan Hamidona, Amitabh Verma, and Reena Vaidyac. "Enhancing Chemical Engineering Education: The Role of Virtual Labs in Bridging Theory and Practice." *Jurnal Kejuruteraan* 38, no. 1 (2026): 25–33.

Reyes, Ronald L., Kristina P. Isleta, Jennifer D. Regala, and Daisy Mae R. Bialba. "Enhancing Experiential Science Learning with Virtual Labs: A Narrative Account of Merits, Challenges, and Implementation Strategies." *Journal of Computer Assisted Learning* 40, no. 6 (2024): 3167–86.

Soyikwa, Lindokuhle, and Sakyiwaa Boateng. "Teaching Physical Sciences in South African Rural High Schools: Learner and Teacher Views about the Challenges." *Issues in Educational Research* 34, no. 4 (2024): 1573–95.

Tadesse, Hagos Nigussie. "The Role of Virtual Laboratories in Advancing Student Learning on Acid–Base Equilibrium." *Chemistry Teacher International* 8, no. 1 (2026): 109–28.

Vygotsky, L. "Social Constructivism." *Mind in Society*, 1978.

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