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Evaluating LabScope: An Immersive VR Chemistry Laboratory for Rwandan Secondary Schools

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Abstract: In Rwanda, where only 25.5% of secondary schools have functioning science laboratories, chemistry students lack the practical experiences required by the Competency-Based Curriculum (CBC). To address this infrastructure alignment shortage, LabScope, a virtual-reality (VR) chemistry laboratory built in Unity 2023.2 and delivered on Meta Quest 2 headsets, offers seven experiments related to the curriculum. This research assessed LabScope using the Educational Design Research (EDR) framework with two stages of preliminary study (n = 75) and a full-fledged usability study (n = 40; 32 students, 8 teachers). Three research questions that were answered by using System Usability Scale (SUS) instruments, observational, and structured teacher interviews, explored the three questions: usability as ease of use and learnability, and satisfaction; conceptual understanding enhancement, engagement, and development of experimental skills; and stakeholder perceptions of the benefit, limitation, and potential improvement of the platform. The results obtained a mean SUS of 84/100, placing LabScope in the range of usability labelled as



excellent. 85% of respondents indicated that they understood chemical reactions better; 78% indicated that they were continually engaged during sessions; and 70% found it easy to navigate. Teachers stated that LabScope's high conformity with the CBC and equitable access to laboratory experiments were the platform's main strengths. Technical reliability was the most frequently cited limitation, with approximately 12% of participants reporting controller connectivity or audio issues during sessions. These findings indicate that immersive VR can serve as a useful, affordable alternative to physical laboratory facilities in low-resource secondary school settings.

Keywords: chemistry education, competency-based curriculum, instructional technology, immersive learning, System Usability Scale, usability testing, virtual reality.

Introduction

It is well known that science education is an important driver of economic development and technological innovation, and access to well-equipped laboratories is a major challenge in most African secondary schools. There are 25.5 per cent working science laboratories in the secondary schools in Rwanda, which means that the overwhelming majority of students are deprived of the practical experimental experiences that are crucial to the conceptual learning of chemistry (Gapfizi et al., 2022; World Bank, 2023). This infrastructure gap has real-world implications: learners who cannot conduct experiments struggle to be conceptually fluent, procedurally competent, and capable of reasoning scientifically, as required by the Competency-Based Curriculum (CBC) in Rwanda (Ministry of Education [MINEDUC], 2019; REB, 2015, 2016).

Emergent technologies, especially extended reality systems that include virtual reality (VR) and augmented reality (AR), are promising options to actual access to labs. Studies have shown that immersive VR settings can effectively simulate physical laboratory learning or supplement it, including conceptual learning, procedural skill training and affective interaction in STEM fields (Makransky et al., 2019a; Tene et al., 2024). These tools are particularly applicable in resource-constrained contexts, where the prices of chemicals, equipment management and safety infrastructure make traditional laboratories expensive to set up. (Niyitanga et al., 2021; Shambare & Jita, 2024).

In 2016, Rwanda introduced the Competency-Based Curriculum (CBC) to equip learners with competencies rather than merely relay knowledge. The CBC focuses on learner-driven strategies, practical skills, and formative evaluation (Twagilimana et al., 2025). Nevertheless, insufficient laboratory facilities have discouraged the practical aspects of this curriculum from being well applied, especially in the science subjects. This study aims to design and assess LabScope, an immersive VR science laboratory platform for practical chemistry education in Kigali secondary schools. The platform has been designed to offer a safe and cost-effective alternative to traditional laboratories that still achieve the educational outcome while remaining compliant with the Rwandan



national curriculum. Although virtual labs (e.g., PhET, Labster) and immersive VR-based platforms (e.g., Prisms VR) demonstrate positive learning and engagement outcomes, their content is not tailored to Rwanda's syllabi. Thus, the gap this project will fill is a lack of a locally contextualised, curriculum-aligned immersive lab that is both viable in Kigali and within the Rwanda school system in general, and purposefully aimed at facilitating the transfer of virtual practice to real-life applications within the framework of CBC.

A systematic comparison of existing VR and virtual laboratory platforms reveals several dimensions along which LabScope is distinctly positioned. PhET Interactive Simulations (University of Colorado Boulder) and Labster offer well-designed chemistry simulations that have demonstrated learning gains in international studies (Radianti et al., 2020); however, both platforms are primarily designed for the North American and European curricula and require reliable internet connectivity, which is a significant constraint in many Rwandan schools. Prisms VR, while delivering high-immersion head-mounted display experiences, is similarly curriculum-agnostic with respect to the Rwandan CBC and employs a subscription-based pricing model that is prohibitive for most public secondary schools in sub-Saharan Africa (Hamilton et al., 2021).

In contrast, LabScope was designed from the ground up with the Rwandan CBC chemistry syllabus as its organisational framework, mapping each of its seven experiments directly to Senior 4-6 content objectives. Its deployment on standalone Meta Quest 2 headsets eliminates the need for internet connectivity during sessions, significantly reducing infrastructure requirements. The platform's cost model, based on a one-time hardware acquisition rather than recurring licensing, offers a more sustainable funding pathway for under-resourced schools. These distinctions justify developing a new platform rather than adapting existing tools, as the contextual relevance, offline operability, and curriculum alignment of LabScope cannot be achieved through simple content modifications to existing platforms (Pellas et al., 2020; Twagilimana et al., 2026).

Virtual reality is a three-dimensional, computer-generated environment accessible to users in real time via a hand controller and head-mounted display (HMD). Unlike passive simulations or video content, VR places the learner within the environment and enables them to interact with objects, move through space and observe processes as though they were physically there. This has provided opportunities for academic learning that a textbook, a teacher demonstration, or even a standard computer simulation cannot provide. Students have the option to dissect a molecule, view a chemical reaction at the molecular level, or practice a laboratory procedure and repeat it without using materials and, most importantly, without safety hazards. The technology reviewed in this paper is LabScope, a full-sized VR chemistry lab designed to support Rwandan secondary school students and implemented on Meta Quest 2 standalone headsets. LabScope is not a universal simulation application - it was created with the specific purpose of providing the CBC-compliant chemistry experiments of Rwanda to schools that lack physical labs. This study aims to assess whether a dedicated platform such as this, in practice, performs well for its target audience.



Research Problem

Although VR-based science instruction is increasingly gaining global attention, there remains a real gap between the technological potential and the educational reality in sub-Saharan African secondary schools. Rwanda Vision 2050 and CBC reform have claimed to expect practical, competency-based science learning (MINEDUC, 2019), but the physical facilities to provide that learning, such as functional laboratories, chemical reagents, and equipment that comply with safety requirements, are not present in the vast majority of schools. This lack of facilities is especially acute in the area of teaching chemistry, where laboratory work is not merely supplementary but is also a direct assessment requirement under the Rwandan CBC. This issue now needs to be carefully analysed, as the CBC requirements for upper secondary have placed an additional burden on teachers and students in schools that cannot afford the practical learning requirements. An approved, context-dependent VR solution could radically change the equity situation in chemistry teaching in Rwanda and serve as a model for educationally constrained education systems across the continent.

Research Focus

This paper focuses on LabScope, an immersive VR chemistry laboratory created to address the lack of access to chemistry laboratories in Rwandan high schools. LabScope was developed in Unity 2023.2 and ran on Meta Quest 2 standalone headsets. It includes seven chemistry experiments based on the CBC of senior four to senior six. The platform combines an AI-assisted context-guiding assistant and a stepwise guidance system to scaffold learners' performance without the need for a teacher to facilitate students' engagement at each level. This paper examines the viability, educational effectiveness and practical acceptance of LabScope by key stakeholders, i.e., students and chemistry teachers, to determine whether it can serve as a substitute for physical laboratory instruction in schools without laboratory facilities.

Research Aim and Research Questions.

This study intends to assess the usability of LabScope and its educational effectiveness among high school students and teachers in Rwanda, and to record stakeholders' perceptions of the product's benefits and limitations, and suggestions for improvement. The study is guided by the following research questions:

RQ1: How usable is the LabScope VR platform to the high school students and teachers as regards ease of use, learnability and satisfaction?

RQ2: How does the application of the LabScope VR platform improve students' learning about chemistry concepts, interest in the subject matter and experimental skills?

RQ3: How do students and teachers perceive the positive and negative aspects of the LabScope VR platform and ways to improve chemistry education through this platform?



Literature Review

The use of Virtual Reality in Chemistry Teaching

The use of VR in science education has produced quite a significant number of results during the last 20 years. It has been demonstrated that simulations and virtual laboratories are more effective in aiding conceptual understanding than conventional learning, especially when students can manipulate variables, observe processes at the molecular level, and receive instant feedback (Tene et al., 2024; Yang et al., 2024). The results of the research by Bonde et al. (2014) indicated that students who had completed virtual laboratory assignments before the actual lab sessions performed significantly better than those taught the subjects in traditional ways. This preparation role is particularly useful in an environment where physical laboratories are accessible only (not always) at certain times.

The study conducted by Makransky and colleagues has contributed to the body of research on the cognitive and motivational aspects of immersive VR for science education. Makransky et al. (2019) have shown that, though high-immersion VR settings increase engagement and presence, their use is contingent on the quality of instructional design and on the preparation of learners relative to desktop simulation. Two later studies (Makransky et al., 2019ab) found that embodied simulations are associated with higher self-efficacy and procedural skill transfer, suggesting that the physical interaction provided by head-mounted displays (HMDs) offers pedagogical benefits beyond their screen-based counterparts. Tene et al. (2024) conducted a systematic review and affirmed that immersive VR technologies yielded significant learning gains in STEM education, with the most frequently reported outcomes being engagement and performance.

Chemistry can be said to be a well-suited subject for VR-based teaching because both procedural precision and conceptual abstraction are equally demanded. Amirbekova et al. (2024) established that VR and AR visualisation contribute significantly to better comprehension and motivation in the learning of chemistry, whereas Qorbani et al. (2024), using a curriculum-based experiment, showed that immersive VR contributes to the understanding of abstract phenomena, not visible to the learners, such as the geometry of the molecules and how they react. More recently, positive results have been reported in the Rwandan setting by Yvan (2026) and Nshimiyimana and Ndayambaje (2025). Their study on the use of technology-enhanced instruction in science confirms the significance of digitally augmented teaching in the CBC.

Using Usability in Education Technology.

Usability is a multi-dimensional concept that covers ease of use, learnability, efficiency, error recovery and user satisfaction (ISO 9241-11, 1998). Usability, in the context of educational technology, is not just a technical requirement but also a condition of long-term pedagogical performance: systems that are cognitively taxing or difficult to navigate impose extraneous cognitive load, disrupting the learning process (Makransky et al., 2016; Vlachogianni & Tselios, 2022). In the



case of VR platforms, usability also includes physical comfort, quality of interaction, and applicability of simulator sickness, which can quickly destroy the usability of the product.

One of the most extensively validated measures of perceived usability is the System Usability Scale (SUS), developed by Brooke (1996), which is used to measure perceived usability in technology domains. The average score is 68, and a score above 80.3 is excellent, with the highest score of 100 being the highest possible usability (Vlachogianni & Tselios, 2022). SUS-derived instruments have been used by Danmali et al. (2024) and Nshimiyimana and Ndayambaje (2025), as they are aimed at assessing educational technology tools in the context of African secondary school settings, noting that the interface design should not presume prior digital literacy.

VR in Educational Resources with Constrained Resources.

Implementing VR in under-resourced settings presents a distinct set of challenges and opportunities. In a scoping review by Mushimiyimana et al. (2025), it was reported that internet connectivity, device access, teachers' digital capabilities, and project management remain the major obstacles to ICT integration in Rwandan schools. According to Twagilimana et al. (2025), though the policy on ICT-in-Education in Rwanda has improved, access to devices and digital infrastructure in laboratories has not yet been developed. In a systematic review, Vlachogianni and Tselios (2022) postulated that usability tests should be conducted based on the digital experience profiles of the intended user groups, because the interface conventions that are intuitively easy for tech-savvy users of such devices may pose learning challenges for novice users.

Against this backdrop, standalone VR headsets such as Meta Quest 2, which do not require a PC or an Internet connection, offer distinct advantages in resource-constrained settings. Danmali et al. (2024) in a Nigerian secondary school setting showed that the introduction of VR in STEM education enhanced engagement and interest in lab practicals, as well as academic performance among at-risk students, highlighting access and equity issues similar to those in Rwandan schools.

Gapfizi et al. (2022) also observed that all-in-one VR devices have offered opportunities for immersive STEM experiences, even in areas lacking reliable broadband infrastructure, noting that platform design should pay close attention to the needs of first-time users and trainers.

Research Gap

Despite the growing body of research on VR-based science education, a clear gap exists in the literature regarding curriculum-aligned, offline-capable VR laboratory tools developed specifically for sub-Saharan African secondary school contexts. Existing studies have primarily been conducted in high-income, well-resourced settings where internet connectivity and technical infrastructure can be assumed (Hamilton et al., 2021; Radianti et al., 2020). Research addressing VR-based laboratory learning in Rwanda and comparable contexts is particularly sparse, with most technology-focused education studies in the country examining ICT integration at a general level rather than subject-specific immersive tools (Habimana et al., 2025; Mushimiyimana et al., 2025). Furthermore, while



usability evaluation of educational VR has been conducted using SUS and related instruments in tertiary settings (Qorbani et al., 2024; Vlachogianni & Tselios, 2022), equivalent studies at the secondary school level in low-resource environments remain rare. This study addresses this gap by evaluating a purpose-built, CBC-aligned VR chemistry laboratory in a Rwandan secondary school context, providing empirical usability and learning-outcome data that directly inform both platform development and digital education policy in the region.

Materials and Methods

Research Design

This research followed the Educational Design Research (EDR) approach that sequentially integrates the development and testing of educational materials and studies the impacts of such materials in real-life contexts (Barab & Squire, 2004). EDR is especially suitable for this study because LabScope, the subject of evaluation and the intended product planned to be deployed in practice, serves both design and empirical purposes. As a result, the study explored how well the platform performed when used by actual users, blending design and research question purposes. The experiment consisted of two phases: a pilot study that would be used to refine the platform and a formal usability study.

The LabScope Platform

LabScope is a VR experience in the form of a chemistry lab intended to support the CBC secondary school chemistry curriculum in Rwanda. Developed with Unity 2023.2 (Unity Technologies, 2024), it runs on Meta Quest 2 standalone VR headsets and includes seven curriculum-based experiments: (1) Sodium Hydroxide Synthesis, (2) Calcium Carbonate Decomposition, (3) Acid-Base Titration, (4) Metal Identification on Flame Tests, (5) Gas Production and Collection, (6) Preparation and Dilution of Solutions, and (7) Chemical Equilibrium Demonstration. An AI assistant using InWorld AI focuses on the context, answers learners' questions and provides the needed guidance. The Book Canvas instructional system provides step-by-step procedural guidance in the VR environment. All learners' interactions within the VR environment are governed by physics-based simulations that model chemical behaviour as realistically as possible, such as colour changes, gas evolution and precipitation reactions.

Sample and Participants

Participants in this study were selected using purposive sampling to ensure representation of the core end-user population; none of the participants had prior experience with VR headsets to guard against prior exposure to the digital technology influencing the study outcomes. Informed consent was obtained from all the participants, and parental or guardian consent was also secured for those who were underage students (below 18 years).



Ethical Statement. This study was conducted in accordance with the ethical guidelines of the Research Ethics Committee (REC) at the African Leadership University.

This study was conducted in two phases. First, a pretest was conducted with a sample of 75 respondents from secondary schools in Kigali, Rwanda, to gather feedback for the iterative development of the platform. This phase was followed by a usability study of the LabScope involving 40 participants, including 32 students (senior four to senior six) and 8 chemistry teachers from the participating schools.

During the preliminary study phase, participant feedback was collected through brief post-session questionnaires and informal verbal observations, focusing on three areas: interface navigation difficulties, the clarity and positioning of BookCanvas instructional prompts, and the responsiveness of the InWorld AI assistant. Based on this feedback, several iterative adjustments were made to the platform before the formal usability study: controller interaction sensitivity was recalibrated, BookCanvas prompt timing was revised to appear earlier in each procedural step, and the AI assistant's audio cue volume was increased to improve audibility in the headset environment.

Instrument and Procedure

Three complementary instruments were used. To start with, the structured questionnaire based on the System Usability Scale (SUS) was used to obtain ratings of ten standardised items on a five-point Likert scale; other items addressed learnability, satisfaction, and immersion. Secondly, research assistants documented the task completion rates, error frequencies, help-seeking behaviours, and navigation patterns during laboratory sessions using a structured observation protocol. Thirdly, teachers participated in semi-structured interviews to obtain detailed perceptions on curriculum alignment, pedagogical usefulness and likely barriers to adoption.

The delimiting factor of each evaluation session was structured into four distinct stages: orientation (about ten minutes dedicated to hardware familiarisation without experiment-specific instruction to assess natural learnability); exploration (twenty minutes of free and unstructured navigation through the experiment using BookCanvas and an AI assistant); structured task (twenty minutes following pre-specified experimental steps guided by an observational checklist); and evaluation (fifteen minutes for questionnaire completion and interviews with teachers). Sessions took place in designated school areas, where research assistants were present to address hardware issues but did not provide content or navigational assistance.

Data Analysis

Descriptive statistics were used to analyse the quantitative data collected from usability questionnaires. SUS scores were calculated according to the standard formula and produced a composite score out of 100 by the participant; the mean scores and standard deviations were determined using the mean of the entire sample and disaggregation by role (student vs teacher). The frequency distributions of separate questionnaire items were determined. Counts and



proportions were used to summarise the observational data. Qualitative data obtained from teacher interviews were analysed through thematic analysis. Coding was conducted both inductively, to explore emergent patterns within the data, and deductively, guided by the three research questions. The analytical procedure adhered to the methodology described by Braun and Clarke (2006).

Results

RQ1: Usability, Ease of Use, Learnability and Satisfaction.

The overall average SUS score among the 40 participants was 84 out of 100 (SD = 7.2), placing LabScope squarely in the excellent range for usability (Vlachogianni & Tselios, 2022). Table 1 shows the distribution of usability ratings on the major dimensions measured in the questionnaire.

Table 1

Usability Evaluation Results (n = 40)

Usability Dimension	Agree / Strongly Agree	Neutral	Disagree / Strongly Disagree
Overall satisfaction ($\geq 4/5$)	85%	10%	5%
High sense of immersion	80%	13%	7%
Intuitive navigation	70%	18%	12%
Equipment interaction ease	68%	20%	12%
Sustained interest throughout session	78%	14%	8%
Technical issues encountered	10-12%	–	–

Note. Ratings reflect participant responses on a five-point Likert scale.

Source: Author's development.

70% of participants rated ease of use positively for navigation, and 68% for equipment interaction. These numbers represent the anticipated learnability curve for a first-time VR-user population phenotype with no prior exposure to immersive head-mounted displays. These were supported by the observation data: about 15 per cent of students needed further prompting within the initial five minutes of exploration, mostly regarding the controller grip and virtual objects and grasping mechanics, but most of the students were able to continue on their own later. The BookCanvas instruction system was also mentioned positively regularly, with participants noting that the in-built instructions minimised the need for an external facilitator.

Patterns of AI assistant use also demonstrated learnability: about 60 per cent of respondents used the AI assistant at the structured task stage, mostly to clarify the steps in the procedure and to confirm the expected findings in the experiment. This trend indicates that the in-system support architecture was effective in offsetting the low levels of previous orientation. The level of satisfaction



was highest among the three aspects of usability, with 85 per cent of respondents scoring four or five out of five. The mean SUS score for teachers (86.4) slightly exceeded that of students (83.2), indicating their ability to contextualise the platform experience within wider instructional systems.

Table 2

SUS Scores Disaggregated by Participant Role (n = 40)

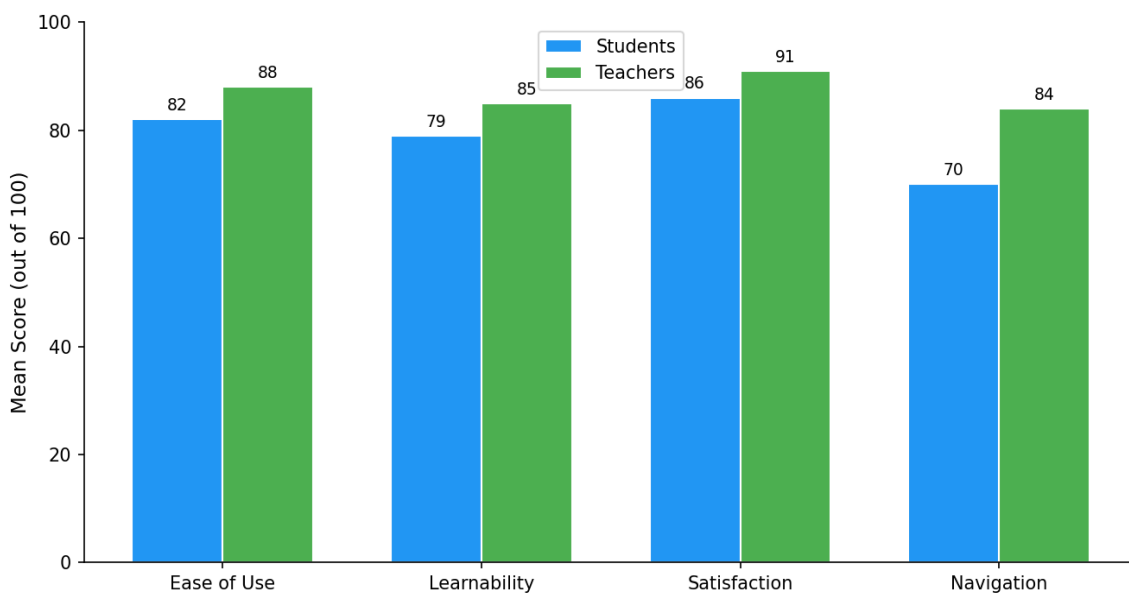
Participant Group	n	Mean SUS Score	SD	Usability Grade
Students	32	83.2	7.5	Excellent
Teachers	8	86.4	5.8	Excellent
Overall	40	84.0	7.2	Excellent

Note. SUS scores above 80.3 fall in the "excellent" usability range (Vlachogianni & Tselios, 2022).

Source: Author's development.

Figure 1

Usability dimension scores by participant role (N = 40).





RQ2: Improvement of Conceptual Learning, Interest, and Practical Abilities.

Figure 2

Mean SUS scores by participant role with usability thresholds.

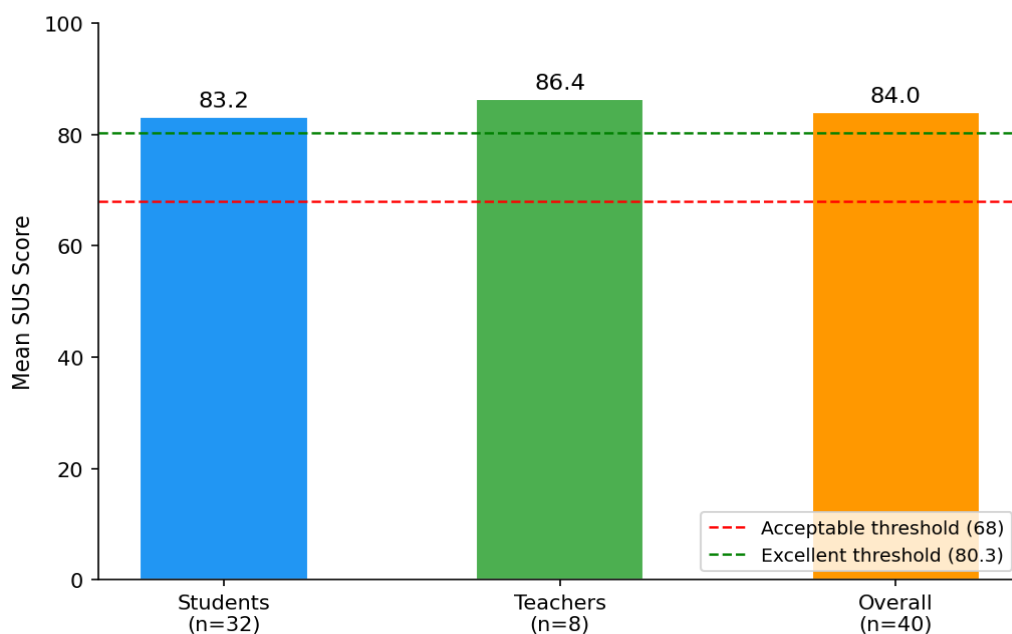


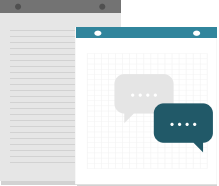
Table 3

Self-Reported Learning Outcomes and Engagement (n = 40)

Learning Indicator	Outcome	Agree / Strongly Agree	Neutral	Disagree / Strongly Disagree
Better understanding of chemical reactions		85%	10%	5%
Improved grasp of previously difficult concepts		68%	20%	12%
Sustained interest throughout session		78%	14%	8%
Successful completion (minimal assistance)	task	80%	12%	8%

Note. Ratings from the post-session questionnaire on a five-point Likert scale. Task completion was measured via structured observation.

Source: Author's development.



Conceptual understanding

Findings on the improvement of conceptual learning revealed that 85% of the respondents indicated that LabScope aided their better comprehension of chemical reactions, while 68% claimed they better understood previously challenging chemistry concepts. Teachers also highlighted that graphically representing chemical reactions, such as acid-base neutralisation and gas evolution, with hands-on interaction made these otherwise abstract concepts clearer and more tangible. Something that the use of textbook diagrams alone could not achieve. One teacher noted that students readily referenced their observations during the VR engagements, when the topics covered during the study period were later introduced in classroom lessons, indicating a transfer of knowledge from the VR environment to classroom use.

From feedback, the platform was especially useful for teaching sub-microscopic phenomena like Sodium Hydroxide Synthesis and Chemical Equilibrium Demonstration experiments. Processes, for instance, ion dissociation and equilibrium shifts, which are typically invisible, were made visible in VR. Several students stated that such processes were qualitatively different when visualised in a dynamic environment, rather than when studying them from still drawings in textbooks. This aligns with the findings of Qorbani et al. (2024) that immersive VR is an efficient method for acquiring abstract chemical knowledge that is otherwise outside the grasp of learners and requires concurrent reasoning across macroscopic, sub-microscopic, and symbolic scales.

Table 4

Summary of Structured Observation Data (n = 40)

Observed Behaviour	Proportion	Phase	Notes
Required initial prompting (controller grip/grasping)	15%	Exploration (first 5 min)	Most self-corrected after brief assistance
Used AI assistant during structured task	60%	Structured task	Primarily for procedural clarification
Completed experiment with minimal assistance	80%	Structured task (end)	Consistent across all 7 experiments
Exhibited off-task behaviour	<5%	All phases	Minimal; engagement remained high
Reported technical issues (controller loss, audio glitch)	10-12%	All phases	Controller connectivity most common

Note. Data was collected by research assistants using a standardised observation checklist during each evaluation session.

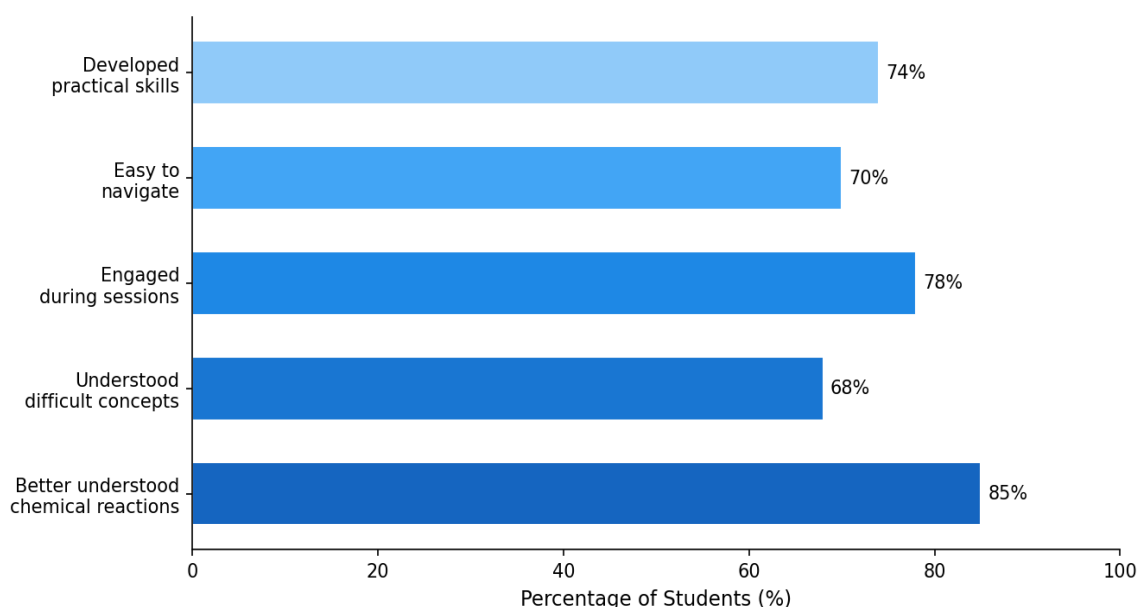
Source: Author's development.



The level of engagement was measured by the proportion of participants who reported sustained interest during the session (78%), while the observed on-task behaviour was measured using the observation checklist. Students demonstrated consistent engagement across all experimental formats, with minimal instances of off-task activity. Task completion data evidenced the development of experimental skills: at the end of the systematic task phase, approximately 80% of participants completed the experimental process with minimal assistance. This finding aligns with Makransky et al. (2019a), who reported similar outcomes in the development of procedural skills using an embodied VR simulator.

Figure 3

Self-reported student learning outcomes and engagement (N = 32).



RQ3: Benefit, Limitations, and Future Improvements Perceptions.

Table 5

Thematic Analysis of Stakeholder Perceptions from Teacher Interviews (n = 8)

Category	Theme	Frequency (of teachers)	8 Representative Response
Benefit	Equitable lab access for under-resourced schools	8/8	"Students who have never entered a lab can now do experiments"
Benefit	Safety in practising with hazardous reagents	6/8	"They can make mistakes without real danger"



Benefit	Alignment with CBC chemistry syllabus (S4-S6) 7/8	"The experiments match what I teach in class"
Limitation	Technical reliability (controller, audio, comfort) 5/8	"The controller disconnected twice during one session"
Limitation	Limited inquiry-based scaffolding 4/8	"It guides procedure but not hypothesis or discussion"
Limitation	Hardware cost and scheduling constraints 3/8	"We only have two headsets for the whole school"
Improvement	Broader experiment coverage (electrochemistry, organic) 6/8	"Add organic chemistry for Senior 6"
Improvement	Guided inquiry modules (hypothesis, data interpretation) 5/8	"Students need to think, not just follow steps"
Improvement	Teacher dashboard for real-time progress tracking 4/8	"I want to see who finished and who struggled"
Improvement	More affordable device options 3/8	"Quest 2 is good but schools need cheaper alternatives"

Note. Themes identified through thematic analysis following Braun and Clarke (2006). Frequency indicates the number of teachers who raised each theme.

Source: Author's development.

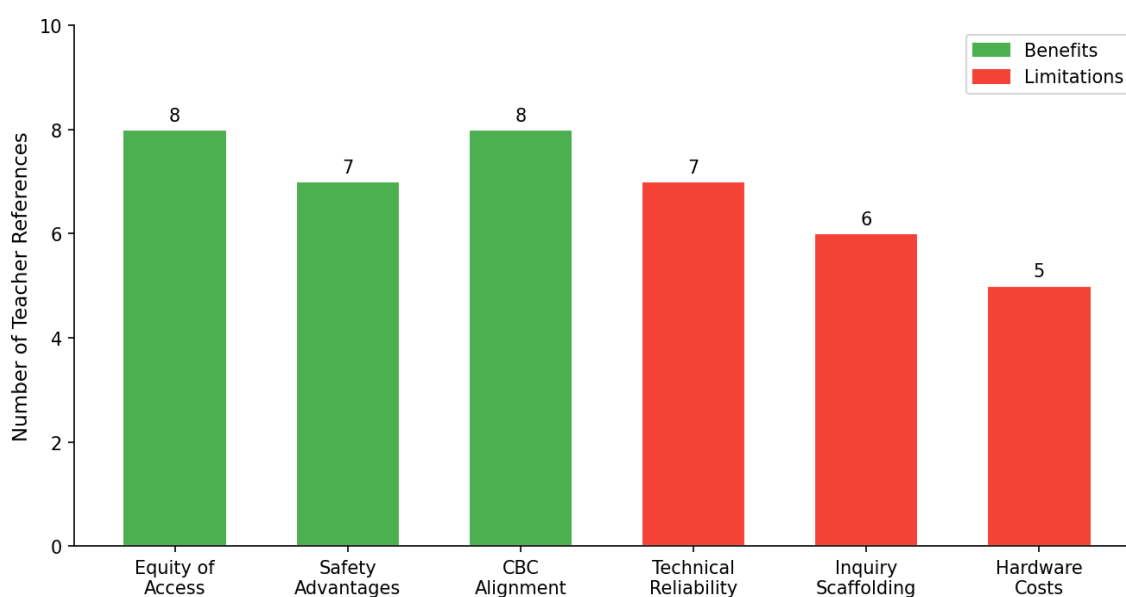
Thematic analysis of teacher interview responses and open-ended questionnaire responses identified three main benefits, three perceived limitations, and four areas of improvement. The main benefit highlighted was that LabScope offered students fair access to lab activities. Teachers from schools without physical labs described how LabScope provided their students with experimental opportunities they would otherwise miss, viewing the platform as an enrichment tool rather than a program aimed at promoting equity. The second advantage was safety: teachers observed that VR can enable students to train with dangerous reagents without risk, thereby developing procedural confidence before actual work is undertaken. Thirdly, the teachers highlighted the alignment of the seven LabScope experiments with the CBC chemistry curriculum for senior four to six.



Technical reliability emerged as the most frequently cited concern, with about 12% of respondents reporting issues such as controller connectivity loss, audio glitches with the AI assistant, and, in a few cases, slight simulator discomfort after prolonged use of the VR headsets. The second weakness was associated with the level of inquiry-based scaffolding: the BookCanvas could guide the procedure but offered no substantial support for hypothesis development and post-experiment discussion, which are higher-order cognitive processes and are assessed in the scoring systems of CBC chemistry. The third limitation was found to be the hardware cost and the shared-device model, which limit scheduling flexibility. Participants recommended several enhancements: offering a wider variety of experiments, such as in electrochemistry and organic chemistry; incorporating guided inquiry modules that encourage hypothesis formation and data interpretation; developing a teacher dashboard to track progress in real time; and ensuring value-neutrality by using affordable device platforms to increase institutional accessibility.

Figure 4

Frequency of themes identified in teacher stakeholder interviews.



Discussion

Usability and Learnability

An average System Usability Score of 84 out of 100 places LabScope alongside well-performing educational VR platforms reviewed in the current literature. Makransky et al. (2016), in the study of VR-based laboratory simulations among university students, reported mean SUS scores between 78-82, a population with higher baseline digital literacy than was observed with the secondary school students in the present study.

This finding that LabScope outperformed these metrics with first-time VR users consequently demonstrates that the scaffolding architecture built into it, the BookCanvas and AI assistant, is



effective in countering the absence of headset experience; therefore, this can be considered an important design validation. This aligns with the assertion by Habimana et al. (2025) that educational technology implemented in low-digital-literacy settings must include high levels of in-platform instructions to reduce the learnability challenges that otherwise hinder interaction.

Learning Outcomes and Engagement.

The results of the learning outcome significantly support other VR-in-chemistry literature overall, but provide contextually specific data for a sub-Saharan African secondary-school setting, which has been hitherto underrepresented in the literature. A percentage of 85% of respondents stated that they understood chemical reactions better, which aligns with the findings of Bonde et al. (2014), who noted that participation in virtual laboratories led to substantive conceptual learning. Besides, the visualisation of sub-microscopic processes on the platform aligns with the curriculum-based research results of Qorbani et al. (2024), which show that immersive VR is an effective conceptual method for learning abstract chemical processes. However, the lack of a control group in the current research limits causal inference; the self-reported gains may reflect perceived, rather than objectively measured, learning outcomes. Future research using quasi-experimental or controlled designs should be used to isolate the independent effect of the platform on chemistry achievement.

Stakeholder Perceptions and Implementation Considerations.

The stakeholder perception findings both confirm and extend prior research on VR deployment in resource-constrained settings. The dominant vision of equity-enabling access as the key advantage is consistent with the fact that infrastructure shortages, teacher capacity, and governance are the key obstacles to ICT integration in Rwandan education, making LabScope a direct policy response to that challenge. Although the technical reliability concerns identified during this study, such as a 12 per cent incident rate, align with previous reports on the early-stage deployment of VR fields (Tene et al., 2024), this study highlights the need to implement robust device-maintenance strategies and adequate technical-support capacity at the school level. A call to more rigorous inquiry-based scaffolding reflects a recognised tension in the literature on VR-learning, in which procedural replication can be at the cost of higher-order scientific thinking, according to Makransky et al. (2019b). Immersive environments that prioritise procedural fidelity at the expense of conceptual challenge may limit transfer to novel problem-solving contexts.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the sample was limited to 40 participants drawn from schools in Kigali, which may not fully represent the diversity of secondary school contexts across Rwanda, particularly rural settings with different infrastructure and teacher capacity profiles. Second, the study relied largely on self-reported measures for learning outcomes and engagement, which are subject to social desirability



bias. Objective performance data, such as pre- and post-test scores, would strengthen the evidence base in future iterations. Third, the relatively short exposure to LabScope during the study period limits conclusions about long-term knowledge retention and skill transfer. Finally, the absence of a control group means that observed gains cannot be attributed exclusively to the VR intervention. The potential impact of social desirability bias on self-reported data is particularly notable: students may have reported higher engagement and learning gains than were objectively experienced, given the novelty of the VR medium and the presence of researchers during sessions. Additionally, the short exposure duration – a single session per participant – limits generalizability to longer-term VR integration programmes; sustained use over a full academic term may yield different patterns of engagement, skill retention, and technical acclimatisation.

Conclusions and Implications

The current study evaluated LabScope, a VR chemistry lab developed for secondary-school students in Rwanda, with respect to three dimensions: usability, educational impact, and stakeholder perception. Evaluation of data from 40 participants yielded three major conclusions. First, LabScope demonstrates high usability for first-time VR users, as supported by a mean SUS score of 84/100 and positive satisfaction ratings from both students and teachers. The in-platform support system effectively compensates for limited prior VR experience. Hence, it will reduce reliance on external facilitation, a key attribute given the very limited ability of many Rwandan teachers to provide VR-specific instruction. Secondly, LabScope produces significant learning outcomes across all evaluated dimensions. The majority of the students reported learning more about chemical reactions and being interested in the entire process during the experiments. Also, observational data attested to the high rates of on-task performance. The ability to visualise sub-microscopic chemistry processes is a direct solution to a long-established conceptual learning barrier in chemistry education. Thirdly, stakeholders' perceptions of LabScope are overall positive. The platform is considered the most valuable attribute of LabScope, identified as the equity-enabling feature that provides students with access to laboratories in schools without an active laboratory.

The implications of these findings are threefold. For practitioners, the results support the integration of LabScope into CBC chemistry delivery as a primary laboratory resource in schools without physical facilities, and as a preparatory and supplementary tool in schools with limited laboratory access. For curriculum designers, the stakeholder feedback identifying gaps in inquiry-based scaffolding points to specific areas where the platform's instructional design could be enhanced to better support the higher-order scientific competencies assessed in CBC examinations. For policymakers, the study provides empirical evidence that standalone VR headsets represent a viable and scalable investment to improve equity in science education in resource-constrained secondary school systems, and warrants consideration within Rwanda's broader digital education strategy.



Suggestions for Future Research

The findings and their limitations indicate several directions for future research. Firstly, a quasi-experimental or randomised controlled study comparing LabScope with comparably matched control groups is needed to ascertain the independent causal effect of the platform on chemistry performance. Secondly, longitudinal research that measures knowledge retention and procedural skill acquisition after a full academic term and after VR-based lab sessions would significantly enhance the evidence base. Third, a study comparing the effectiveness of LabScope in a rural school where infrastructure and teacher capacity could differ significantly from those of the sampled schools in the city of Kigali would provide information on the external validity of the platform and assess its generalisability. Finally, research into the most accurate sequencing of VR experimentation within broader lesson structures, specifically how VR-based and physical laboratory experiences interact, would inform evidence-based implementation guidance to schools and curriculum authorities.

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Conflict of Interest

The authors declare no conflict of interest. The LabScope platform was developed as part of an academic research project with no commercial sponsorship or financial interest from any external organisation.

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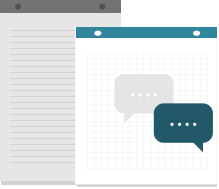
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