



Exploring the Perception of Science Teachers in Integration of VLS (Virtual Laboratories) in Science Education: Literature Review

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ABSTRACT

This study explores science teachers' perceptions of integrating virtual laboratories (VLS) in science education using a literature review methodology. A systematic process of identifying, screening, and analyzing relevant studies was employed to synthesize existing findings. Results indicate that science teachers generally have positive attitudes toward VLS, recognizing their potential to enhance conceptual understanding, engagement, and higher-order thinking skills. VLS are considered flexible and innovative tools that can supplement or partially replace traditional laboratories. However, their actual implementation remains limited due to challenges such as inadequate infrastructure, limited teacher training, and lack of institutional support. These constraints create a gap between positive perceptions and actual practice. The study highlights the need for continuous professional development, improved resources, and supportive policies to strengthen the integration of VLS in science education

INTRODUCTION

The virtual laboratories (VLs) are tools that shift science learning into new horizons and opportunities. Shambare and Jita (2025) mentioned that the use of virtual laboratories (VLs) is one of the innovations that emerged due to the increasing integration of technology in science education. They also address the limitations of traditional laboratory settings (Vergara et al., 2020). VLs have evolved from conceptual tools into practical resources. They simulate real-world experiments and offer scalable and cost-effective alternatives to physical laboratories (Ntinda et al., 2021; Vergara et al., 2020).

During the COVID-19 pandemic, the adoption and use of VLs accelerated, as they showed potential in sustaining laboratory instruction amid disruptions in science laboratory classes conducted online (Shambare & Simuja, 2024; Christabel & Prawira, 2023). In line with this, Shambare et al. (2022) noted a significant shift in many rural schools toward the use of VLs. However, Nzabahimana et al. (2024) reported that these schools face common challenges such as inadequate infrastructure and limited access to laboratory-related resources, underscoring the practical importance of VLs in expanding science learning opportunities. Despite their promise, Sukmawati et al. (2024) found that a persistent problem lies in the uneven acceptance and adoption of VLs by science teachers, which critically affects their effective integration into the curriculum.

Existing literature shows that teachers generally have a positive attitude toward VLs and are willing to adopt them (Jain & Kaur, 2022). However, there remains a knowledge gap regarding teachers' perceptions of VL integration, particularly across diverse socio-economic and geographic contexts (Shambare & Simuja, 2024; Shambare, 2022). Additionally, some skepticism exists about the ability of VLs to replicate hands-on experiences and their effectiveness as complementary tools in laboratory instruction (Navarro et al., 2024). These gaps have significant consequences, as insufficient teacher acceptance may lead to the underutilization of VLs in science teaching and learning (Shambare & Jita, 2025; Sukmawati et al., 2024).

It is evident that the integration of VLs in science education remains a developing field, with existing studies still limited in scope and depth. While initial efforts have explored the potential of VLs, further investigation is needed to identify factors influencing their acceptance and use, as well as to evaluate the role of teacher training and infrastructural support in facilitating their adoption.

THEORETICAL REVIEW

The integration of virtual laboratories (VLs) in science education is supported by several educational theories that enhance learning experiences and outcomes in science classes. These include the Technology Acceptance Model (TAM), constructivist learning theory, and experiential learning theory, all of which emphasize interactive, immersive, and learner-centered approaches to education.

The Technology Acceptance Model (TAM) focuses on users' perceptions and the accessibility of VLs. Shambare and Simuja (2024) stated that the acceptance and use of VLs are influenced by teachers' perceptions and experiences, highlighting the need for adequate training and infrastructure. In

terms of accessibility, VLS provide access to high-quality laboratory experiences, especially in resource-limited settings.

Constructivist learning theory suggests that VLS promote active learning by allowing students to engage in hands-on experimentation through digital platforms. This enables learners to construct their own knowledge through interaction with scientific concepts (Meronda et al., 2025). Ayyubi et al. (2024) added that VLS simulate real-world laboratory experiences, effectively bridging the gap between theory and practice and promoting deeper learning.

Experiential learning theory emphasizes learning through experience. Rosli and Ishak (2024) explained that VLS allow students to conduct experiments independently, thereby enhancing their practical skills and competencies in scientific inquiry. Moreover, Meronda et al. (2025) found that students using VLS achieve better learning outcomes compared to traditional methods, fostering critical thinking and scientific literacy.

In summary, these theories collectively explain the integration of virtual laboratories in science education. The Technology Acceptance Model highlights the importance of teachers' decisions to adopt VLS, while constructivist and experiential learning theories explain how these tools enhance student learning through active engagement and simulated hands-on experiences.

Conceptual Framework

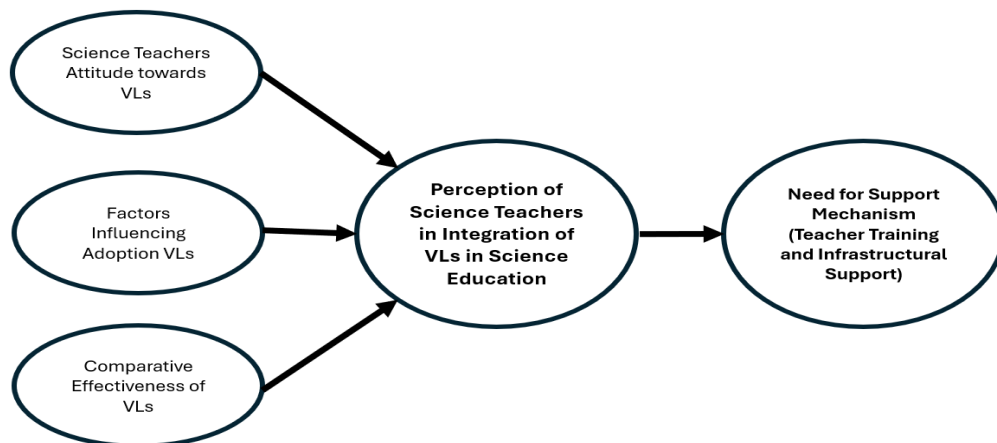


Figure 1. The conceptual framework of Exploring the Perception of Science Teachers in Integration of VLS (Virtual Laboratories) in Science Education

The Figure 1 presents the conceptual framework of the study, illustrating how science teachers' perceptions of integrating Virtual Laboratories (VLS) in science education are shaped by three factors: (1) teachers' attitudes toward VLS, (2) factors influencing the adoption of VLS, and (3) the comparative effectiveness of VLS in science classes.

These factors collectively influence the overall perception of science teachers regarding the integration of VLS in science education. This perception highlights the need for support mechanisms, such as teacher training and policy reforms, to ensure the sustainable and effective use of VLS in science education.

METHODOLOGY

This study utilized a literature review method, which comprehensively analyzes existing literature on a specific topic. It aims to identify research gaps, synthesize information, and provide context for future research endeavors (Hazari, 2023). Additionally, it summarizes existing studies and identifies practical and theoretical issues that guide new research by addressing gaps in the literature (Victoriano, 2025).

The literature review process involved several stages: (1) determining the research problem, (2) searching for relevant literature, (3) reading existing studies, (4) reviewing the content, (5) synthesizing findings, and (6) rewriting the results into new insights. The Scispace website (<https://typeset.io/>) was used to facilitate the identification of relevant literature aligned with the research theme.

During the screening process, inclusion and exclusion criteria were applied to obtain a focused set of studies, along with citation chaining to identify additional relevant research. A total of 411 research papers were initially identified based on the following queries: (1) science teachers' perceptions of virtual laboratories, (2) the impact of virtual laboratories on science teaching methodologies and teacher training programs, and (3) the integration of virtual laboratories in teacher training and its effects on pedagogical approaches.

Both backward and forward citation chaining were utilized. Backward citation chaining examined reference lists to identify earlier studies, while forward citation chaining identified more recent research. This process yielded an additional 45 studies.

In total, 456 candidate research papers were gathered. These studies underwent relevance screening based on predefined criteria, including alignment with research objectives, focus on science education, and discussion of VL integration. After applying relevance ranking and full-text assessment, 26 studies were identified as highly relevant and included in the final analysis.

RESULTS AND DISCUSSION

Science Teachers Attitude towards VLS

Most studies indicate that science teachers generally have positive attitudes toward virtual laboratories (Nandani & Raturi, 2024; Santos & Prudente, 2022). Shambare and Jita (2025) reported a strong intention among teachers to adopt VLS, particularly due to their ability to address resource constraints in rural and marginalized schools. Rahmadani et al. (2021) noted that teachers view VLS as practical tools that can supplement or partially replace traditional laboratories. Similarly, Navarro et al. (2024) explained that VLS can be used for pre-laboratory preparation, concept reinforcement, and blended learning approaches.

VLS also enhance student engagement and motivation. Mloi and Matabane (2024) found that VLS improve conceptual understanding, motivation, and engagement while supporting inquiry-based and individualized learning. Kirneva (2022) and Rahmadani et al. (2021) emphasized their role in developing higher-order thinking skills. However, teachers' perceptions vary depending on their experience, familiarity, and exposure to VLS. Sukmawati et al. (2024) noted that experienced teachers tend to show stronger acceptance due to habitual use.

Despite these positive views, actual adoption remains limited. Shambare and Jita (2025) and Nzabahimana et al. (2024) reported that intentions do not always translate into sustained use. Shambare and Simuja (2024) identified a gap between perceived usefulness and actual integration due to contextual barriers. Additionally, Byeon (2024) and Espenbetova et al. (2024) found that some teachers experience negative or mixed perceptions due to lack of skills, usability issues, and unfamiliarity.

Overall, science teachers demonstrate positive perceptions of VLs; however, their integration in classrooms remains limited. This results in a persistent gap between perceived usefulness and actual implementation.

Factors Affecting Adoption of VLs

The adoption of VLs is influenced by several factors, including teacher acceptance and perception, teacher readiness and training, infrastructure and resources, social and institutional influence, and pedagogical and curriculum factors.

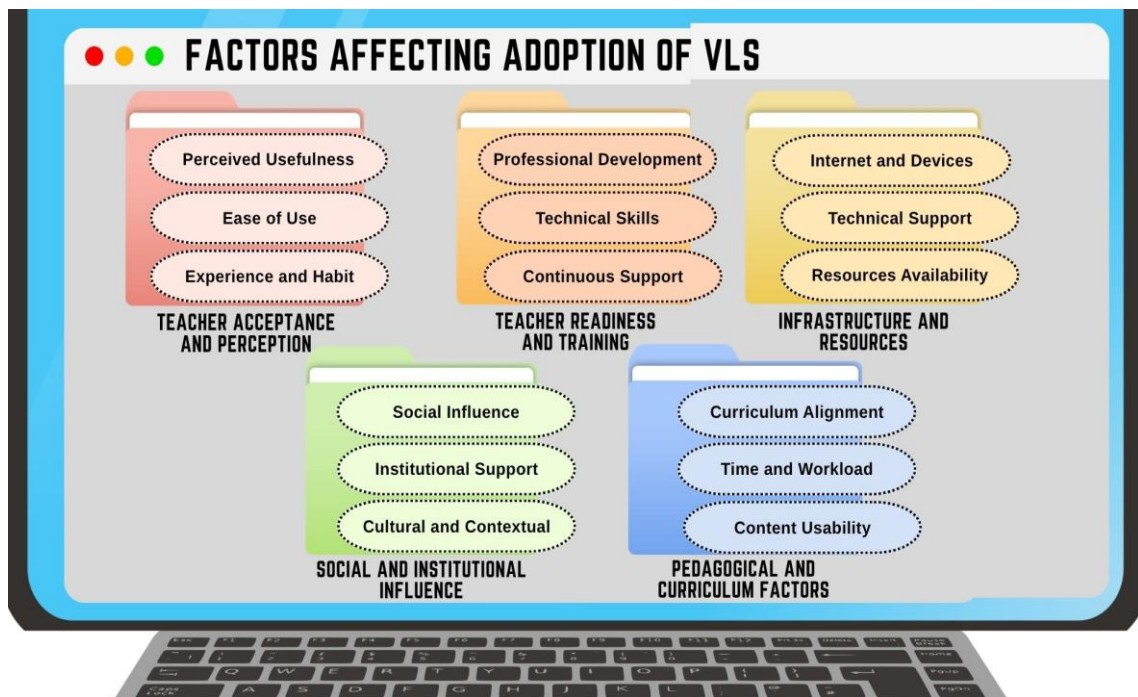


Figure 2. Factors Affecting Adoption of Virtual Laboratories (VLs)

The teacher acceptance and perception cover the perceived usefulness, ease of use and experience and habit. With perceived usefulness, Shambare & Jita (2025) and Santos & Prudente (2022) determine the perceived usefulness generally view VLs as useful, especially in resource-limited settings and positive perception increases intention to adopt. With the ease of use, Kolil & Achuthan (2022) mentioned that VLs are user-friendly platforms that enhance adoption, however complex systems discourage use. For the experience and habit, Sukmawati et al. (2024) found out that experienced teachers show stronger habitual use while novice teachers rely more on training.

Science teachers adoption of VLs is primarily driven by their perception of usefulness and ease of use. Also, Their positive attitude increases the willingness to integrate VLs. Still, without sufficient exposure, familiarity and confidence to explore VLs are the factors that the actual usage may remain limited in science class.

The scope of teacher readiness and training are professional development, technical skills and continuous support. For the professional development, the training significantly improves confidence, competence and actual VLs usage (Nandani & Raturi, 2024; Achuthan et al., 2023). With the technical skills, Huamán (2022) explain that lack of ICT skills limits adoption even when attitudes are positive. Further, the continuous support must be an on-going training workshop are necessary for sustained integration (Pantina et al., 2018).

Teachers readiness and trainings are the critical enablers that significantly influences the adoption of science teachers in integrating VLs in science class. With this, it is evidently that teachers who receive sustained training are more likely to effectively and consistently integrate VLs into their science instruction.

The infrastructure and resources include the internet and devices, technical support and resource availability. With the internet and devices, Nzabahimana et al. (2024) elaborate that limited to acces to internet, computers, devices is a major barrier, specifically in rural schools. The lack of technical support reduces teachers' willingness to use VLs (Ramli & Saleh, 2019). With the resource availability, Shambare et al. (2022) mentioned that schools without physical laboratories are more motivated to adopt VLs.

To access a reliable technological infrastructure is a fundamental requirement for the adoption of VLs. However, the limitations with these resources pose a major barrier, specifically in under-resourced educational settings.

The social and institutional influence range social influence, institutional support, and cultural and contextual factors. The social influence refers to the peers, learners and even family influence teachers' adoption behaviour (Shambare & Jita, 2025). With the instituional support, Santos & Prudente (2022) refers to the administrative support, policies and funding strongly affect adoption. Also, the cultural and contextual factors is the adoption varies by region, school type and socio-economic context of the school (Shambare & Simuja, 2024).

The external influences shaped the teacher's decision to adopt VLs - the administrative support, institutional policies, peer collaboration and broader socio-cultural context. With a strong organizational backing fosters, it can help and guide teachers to accept and sustained the use of VLs.

The pedagogical and curriculum factors consider the curriculum alignment, time and workload, and content usability. The VLs must align with the curriculum and inquiry-based learning to be adopted (Byeon, 2024). With the time and workload, Bo et al. (2018), the science teachers face time constraint and pressure to cover content and limiting VLs integration in science class. Further, the poorly designed or non-interactive VLs content discourages to use (Lynch & Ghergulescu, 2017).

The VLS integration depends with the alignment of the curriculum goals, instructional strategies and time availability. The teachers are more likely to adopt and utilize VLS when it is pedagogically relevant, easy-to-use and supportive of learning objectives of the lesson.

Comparative Effectiveness of VLS

Table 1: The Comparative Effectiveness of Virtual Laboratories (VLS)

Theme	Subtheme	Author(s)
Learning Outcomes	Conceptual Understanding	Navarro et al. (2024)
	Academic Performance	Tsihouridis et al. (2019)
Student Engagement and Motivation	Increased Motivation	Diwakar et al. (2023)
	Interactive Learning	Diwakar et al. (2023)
Accessibility and Practical Advantages	Cost and Safety	Achuthan et al. (2014)
	Accessibility	Ntinda et al. (2021). Kirneva (2022)
Skill Development	High-Order Thinking	Kirneva (2022)
	Practical Skills Limitation	Abdelwahed (2014); Jain & Kaur (2022)
Variability of Effectiveness	Subject and Level Differences	Tsihouridis et al. (2019)
	Technology Quality	Tsihouridis et al. (2019)

The comparative effectiveness of VLS relative to traditional laboratories mainly focuses on the learning outcomes, student engagement and motivation, accessibility and practical advantages, skills development and variability effectiveness.

The learning outcomes cover conceptual understanding and academic performance. Navarro et al. (2024) mentioned that VLS enhance the understanding of abstract concepts in science through visualization and simulation. Also, VLS can be equally effective as traditional science laboratories in learning outcomes (Tsihouridis et al., 2019).

The student engagement and motivation includes the increases in motivation and interactive learning. Diwakar et al. (2023) highlighted that VLS

increases engagement, interest and intrinsic motivation of the teachers and learners. Further, VLs promotes active and inquiry -based learning experiences.

The accessibility and practical advantages refer to the cost & safety. Ntinda et al. (2021) mentioned that VLs reduce cost, eliminate hazards and allow repeated experiment. Moreover, it is useful in school lacking physical science laboratories or proper equipments in a specific science laboratory activity.

The skill development are the higher-order thinking and practice skills limitations. Kirneva (2022) noted that VLs support critical thinking, inquiry and research skills. Still, Jain & Kaur (2022) consider that VLs are limited in developing hands-on, tactile and manipulative skills.

The variability of effectiveness consider the subject & level differences and technology quality. Tsihouridis et al. (2019) elaborated that the effectiveness of VLs varies depend on the subject-matter or the science strand. Also, more advanced VLs, such Augmented Reality (AR), Virtual Reality (VR) and the like improve effectiveness although these requires higher resouces.

The VLs laboratories (VLs) are generally effective as traditional laboratories in improving the conceptual understanding and student engagement through interactive and inquiry-based learning. It offers significant advantages in terms of accessibility, cost and safety. Yet, the limitation in developing hand-on skills and variability of their effectiveness depending on the content and technology quality.

CONCLUSIONS AND RECOMMENDATIONS

The literature reviewed reveals that science teachers generally hold a positive perception toward the integration of virtual laboratories (VLs) in science education. VLs are widely recognized an innovative and flexible instructional tool that enhance conceptual understanding, students' engagement and motivation. It supports inquiry-based and higher-order thinking skills in science class.

Further, science teachers acknowledge their values as supplementary or partial replacements for traditional laboratories. Despite these favorable perceptions, the actual adoption and sustained integration of VLs of science teachers in science class are limited due to contextual and systemic challenges. With this, there remain a persistent gap between science teachers' positive perceptions of VLs and their effective implementation in science teaching and learning process.

These are the following recommendations that can guide science teachers, school administrators and curriculum planners and policymakers toward improving the integration of virtual laboratories (VLs) in science education:

- Provide continuous training for science teachers on how to use VLs to improve their skills and confidence
- Ensure schools to have strong support, such as stable internet connection, enough devices and technical assistance, specifically in low-resource areas.
- Align the curriculum to ensure the integration of VLs intro science instruction and inquiry-based learning activities.
- Create a school policies and support systems that encourage the use of VLs, include funding and clear guidelines.

- Encourage the use of both VLS and hand-on laboratory activities to improve understanding and practical skills.

FURTHER STUDY

This research limited to a review of existing literature and does not involve primary data collection. Future studies should explore the gap between science teachers' positive perceptions of virtual laboratories (VLS) and their actual implementation in classroom setting, experimental designs to measure the impact of VLS on students' performance and compare result across different school settings. Also, they may evaluate science teacher training program and blended laboratory approaches to determine effective strategies for sustained integration of VLS. These efforts can contribute to bridging the gap between positive perception, actual practice and enhance the quality of science teaching and learning.

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