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Virtual Labs in Science Teaching: Sri Lankan Teachers' Perspectives and Challenges

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Abstract

This study examines Sri Lankan Science teachers' perspectives on using virtual labs (VLs) in Science teaching, focusing on challenges and their impact on student engagement and learning outcomes. Data from 150 teachers in 1AB, 1C, and Type II schools across urban and rural areas were collected through surveys and semi-structured interviews. Results revealed disparities in perceptions and implementation of VLs based on school type and location. Teachers in 1AB schools had the highest perception scores ($M = 3.9$, $SD = 0.8$), while Type II schools scored the lowest ($M = 2.2$, $SD = 0.7$). ANOVA analysis confirmed significant differences across school types ($F(2,147) = 15.43$, $p < .001$). Rural schools faced more challenges, with 65% of teachers lacking reliable internet compared to 25% in urban schools. Only 30% of Type II school teachers attended training, compared to 85% in 1AB schools. Teacher training showed a strong positive correlation ($r = 0.72$) with VL effectiveness. Urban teachers reported better resource access, with 75% having reliable internet access compared to 35% in rural areas. Teachers highlighted VLs' potential to boost engagement, particularly in 1AB schools ($M = 3.8$). However, engagement was minimal in Type II schools ($M = 2.4$), highlighting the need for targeted interventions. Recommendations include improving infrastructure, enhancing teacher training, and adopting blended learning to ensure equitable access and effective VL integration across schools.

Keywords: Virtual labs, Science teacher, teacher perspectives, student engagement, teacher training

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Introduction

The integration of technology into education has significantly transformed the landscape of teaching and learning across the globe. Among various technological innovations, virtual laboratories (VLs) have emerged as a valuable tool in enhancing Science education, providing students with opportunities to engage in experiments and simulations that would otherwise be impractical due to constraints like limited resources, safety concerns, or time restrictions (Cheng & Tsai, 2020; Bell et al., 2014). VLs, which use computer simulations to replicate real-world laboratory experiences, allow students to experiment in a controlled, safe, and flexible environment, offering an alternative to traditional hands-on experiments (Makransky et al., 2019).

In the Sri Lankan context, the application of VLs in Science education is relatively recent but increasingly recognized as a potential solution to the challenges faced by educators. These challenges include inadequate physical infrastructure, a shortage of teaching resources, and difficulties in engaging students in complex scientific concepts through conventional methods (Perera & Alwis, 2021). Studies have shown that virtual labs can bridge the gap between theoretical knowledge and practical application, enabling students to develop critical thinking and problem-solving skills while fostering deeper engagement with the subject matter (Mehta et al., 2018; Serhan, 2021).

Despite their promise, the adoption of VLs in Sri Lankan schools faces several challenges. These include limited access to reliable internet connections, the lack of adequate training for teachers, and resistance to change from traditional teaching methods (Ranaweera & Herath, 2022). Furthermore, while VLs are lauded for their ability to simulate a variety of scientific phenomena, concerns have been raised regarding their effectiveness in replicating the tactile and sensory experiences of real-world laboratory work (Heimlich & Litteken, 2020). Therefore, while VLs offer significant potential, their implementation in Sri Lankan schools requires a nuanced understanding of local perspectives and the specific barriers teachers face in utilizing these tools effectively.

The objective of this paper is to explore the perspectives and challenges faced by Sri Lankan school teachers in integrating VLs into Science teaching. By analysing both the potential benefits and obstacles to the effective use of VLs, this study aims to provide a comprehensive overview of how VLs could be utilised to enhance Science education in Sri Lanka. Through a survey of Science teachers across various regions, this research seeks to identify key factors influencing the successful adoption of VLs and offer recommendations for overcoming the existing challenges.

Objectives of the Study

i. To identify and compare the perceptions of Sri Lankan Science teachers from different school types (1AB, 1C, and Type II) regarding the effectiveness of virtual laboratories in enhancing Science education.
ii. To explore the challenges faced by Science teachers in urban and rural schools in adopting and implementing virtual laboratories for Science education.
iii. To investigate the relationship between teacher training and the effective use of virtual laboratories in Science teaching across different school types.

iv. To analyze the perceived impact of virtual laboratories on students' engagement and learning outcomes in Science, as reported by teachers in different school types and locations.

Review of Literature

The integration of virtual labs (VLs) into Science education has emerged as a promising solution to address the limitations posed by traditional laboratories, particularly in resource-constrained environments. VLs offer students the opportunity to engage in simulations of scientific experiments, providing a platform for exploration and learning without the need for physical equipment or laboratory space (Bell et al., 2014). In Sri Lanka, where many schools face infrastructure limitations, VLs are seen as a potential solution to improve Science education, particularly in schools with inadequate physical resources (Perera & Alwis, 2021). However, the effective implementation of VLs depends on various factors such as the availability of technology, teacher readiness, and geographical context (Makransky et al., 2019).

In the Sri Lankan context, schools are categorized into different types based on their facilities, academic performance, and resources. 1AB schools, which are typically well-funded and located in urban or semi-urban areas, have greater access to technology and infrastructure compared to 1C and Type II schools, which often face resource constraints (Ranaweera & Herath, 2022).

Geographic location plays a crucial role in determining the extent to which VLs can be integrated into Science teaching. Urban schools are generally more equipped with modern technologies, stable internet connectivity, and a supportive infrastructure for integrating educational technologies into their curriculum (Cheng & Tsai, 2020). On the other hand, rural schools face significant challenges in terms of infrastructure, including poor internet connectivity and limited access to digital devices. Studies have shown that teachers in rural settings are less likely to use VLs due to these constraints, and even when they do, the effectiveness of these tools is often compromised (Serhan, 2021).

Theoretical Framework

The theoretical framework for this study is based on key theory and model that inform the integration of educational technologies, specifically VLs into teaching in Science education. This framework incorporates Technology Acceptance Model (TAM), and Diffusion of Innovation Theory, both of which provide a comprehensive lens for understanding how technology, particularly VLs, is adopted and integrated into diverse educational contexts.

TAM, developed by Davis (1989), posits that the acceptance and use of new technologies are influenced by two key factors: perceived ease of use and perceived usefulness. According to this model, when individuals believe that technology is easy to use and beneficial for their teaching practice, they are more likely to adopt it (Davis, 1989).

In the context of this study, TAM will be applied to examine how teachers in different types of schools (1AB, 1C, and Type II) perceive VLs in terms of their usability and effectiveness in enhancing Science education. TAM will also help explain how teachers' attitudes toward VLs influence their willingness to integrate these technologies into their Science lessons.

Diffusion of Innovation Theory, developed by Rogers (2003), explores how, why, and at what rate new ideas and technologies spread within a society or organization. This theory is particularly useful for understanding the adoption and diffusion of VLs in schools, where the pace and success of adoption depend on several factors: the perceived advantages of the innovation, the compatibility with existing practices, the simplicity of use, and the observable results (Rogers, 2003). In the context of this study, this theory will help explain the adoption process of VLs across different school types (1AB, 1C, and Type II) and geographical locations (urban vs. rural).

Methodology

This study adopted a survey research design, combining both quantitative and qualitative approaches to provide a comprehensive understanding of the factors influencing the adoption of VLs in Sri Lankan schools. The quantitative component involved the use of survey questionnaires to collect numerical data on teachers' perceptions, experiences, and challenges in using VLs. The qualitative component employed semi-structured interviews to gather in-depth insights into the teachers' views, experiences, and contextual factors that shape their use of VLs in the classroom.

Participants

The study sample consists of Science teachers from schools across Sri Lanka, representing a diverse range of school types and geographical locations:

Table 1

Participants based on school types and geographical location

School Type	Urban Schools	Rural Schools
1AB	25	25
1C	25	25
Type II	25	25

The participants were selected using stratified random sampling to ensure proportional representation of teachers from each school type. In total, the study aims to include 150 Science teachers (approximately, 50 from each category: 1AB, 1C, and Type II schools). Additionally, the study includes a subset of 20 teachers (approximately, 10 urban and 10 rural) who participated in semi-structured interviews to provide deeper insights into the challenges and opportunities in adopting virtual labs in their classrooms.

Data Collection

A structured survey questionnaire was developed based on TAM and Diffusion of Innovation Theory, as outlined in the theoretical framework. The survey was administered in person, depending on the teachers' access to technology, with a response time of approximately 30 minutes. In addition to the survey, semi-structured interviews were conducted with a subset of 20 teachers (10 from urban schools and 10 from rural schools) to provide in-depth insights into their experiences and perceptions of using virtual labs. The interviews were conducted in Sinhala or Tamil, depending on the teacher's preference, and were audio-recorded with the consent of the participants. Each interview lasted approximately for 30-45 minutes.

Data Analysis

The quantitative data collected from the survey questionnaire was analyzed using descriptive statistics and inferential statistics to examine the teachers' perceptions of VLs across different school types and locations.

The main statistical analyses were as follows

Descriptive Statistics: Frequency distributions, means, and standard deviations were calculated to summarize teachers' responses on the perceptions of the ease of use, usefulness, and impact of VLs on teaching and learning.

Inferential Statistics: To test significant differences in teachers' perceptions based on the school type (1AB, 1C, and Type II) and location (urban vs. rural), ANOVA (Analysis of Variance) was used. Additionally, correlation analysis was conducted to examine the relationship between teachers' technological confidence, training, and the perceived success of VL adoption.

The qualitative data from the semi-structured interviews were analyzed using thematic analysis. The findings from the thematic analysis were triangulated with the quantitative results to provide a more nuanced understanding of the factors that influence the use of VLs in Sri Lankan schools.

Ethical Considerations

Ethical approval for the study was obtained from the relevant educational authorities. Participation was voluntary, and all participants were informed of the study's purpose and their right to confidentiality and anonymity. Consent forms were provided to teachers, and interviewees were assured that their responses will be kept confidential and used solely for research purposes. Data were stored securely, and personal identifiers were removed to ensure privacy.

Limitations of the Study

While this study aimed to provide a comprehensive understanding of VL adoption across different school types and locations, there were several limitations:

- The study was limited to Science teachers, and findings may not be generalizable to other subject areas.
- The sample size, though representative, may not have captured all the nuances of VL adoption in Sri Lanka's diverse educational landscape.
- Data collected through self-report (survey and interviews) may be subject to response biases, such as social desirability or teachers' subjective interpretations.

Results and Discussion

Demographic characteristics of the participants

The demographic characteristics of the participants are presented in Table 2. Participants were evenly distributed across three school types, with 33.33% from each category: 1AB, 1C, and Type II. The sample was equally divided between urban and rural locations, with 50% from each setting.

Table 2

Demographic distribution of participants by school type, location, years of experience, and age group

Demographic Factor	Categories	Count	Percentage
School Type	1AB	50	33.33%
	1C	50	33.33%
	Type II	50	33.33%
Location	Urban	75	50.00%
	Rural	75	50.00%
Years of Experience	Less than 5 years	34	22.67%
	5-10 years	68	45.33%
	More than 10 years	48	32.00%
Age Group	Below 30	22	14.67%
	30-40	47	31.33%
	Above 40	81	54.00%

Perceptions of Science teachers on the effectiveness of VLs across different school types

The effectiveness of VLs in enhancing Science education is perceived differently by teachers from 1AB, 1C, and Type II schools in Sri Lanka. The findings from both quantitative and qualitative analyses are presented below.

Quantitative Findings

Table 3

Descriptive statistics of perceptions of VLs by school type

School Type	1AB	1C	Type II
Frequency	50	50	50
Mean Score	3.9	2.9	2.2
Standard Deviation	0.8	0.9	0.7

Table 3 summarizes the descriptive statistics for Sri Lankan school teachers' perceptions of VLs in teaching Science, categorized by school type (1AB, 1C, and Type II). Teachers from 1AB schools reported the most favourable perceptions of VLs (M = 3.9, SD = 0.8), followed by teachers from 1C schools (M = 2.9, SD = 0.9). Teachers from Type II schools reported the least favourable perceptions (M = 2.2, SD = 0.7).

Table 4

Comparative usefulness of virtual vs. traditional laboratories by school type

School Type	Much less useful	Less useful	About the Same	More useful	Much more useful
1AB	5%	10%	20%	40%	25%
1C	15%	30%	35%	15%	5%
Type II	40%	30%	20%	5%	5%

Table 4 illustrates teachers' perceptions of the comparative usefulness of VLs versus traditional laboratories, categorized by school type (1AB, 1C, and Type II). A substantial proportion of teachers in 1AB schools viewed VLs as more useful, with 40% indicating "More useful" and 25% indicating "Much more useful." In contrast, teachers in 1C schools showed mixed opinions, with 35% reporting "About the same," and a higher percentage perceiving VLs as less useful (30% "Less useful" and 15% "Much less useful").

Teachers from Type II schools largely viewed VLs less favourably, with 40% indicating "Much Less Useful" and 30% reporting "Less Useful." Only a small percentage (5%) found VLs "More Useful" or "Much More Useful" compared to traditional laboratories.

Table 5

ANOVA results for perceptions of VL effectiveness by school type

Source	SS	df	MS	F	p
Between Groups	45.6	2	22.8	15.43	< .001
Within Groups	132.4	147	0.9		
Total	178	149			

Table 5 summarizes the results of a one-way Analysis of Variance (ANOVA) examining the differences in teachers' perceptions of virtual laboratory effectiveness across the three school types (1AB, 1C, and Type II). The analysis revealed a statistically significant difference among the groups, $F (2, 147) = 15.43$, $p < .001$. This finding indicates that perceptions of VL effectiveness vary significantly depending on the school type.

Qualitative Findings

Teachers expressed that VLs are highly effective in enhancing students' understanding of complex scientific concepts through interactive simulations. One teacher stated, *"Students can manipulate variables and see immediate results, which is not always possible in traditional labs."* Teachers highlighted the value of VLs in creating engaging, interactive learning environments, particularly where physical resources are limited.

However, perceptions of VLs' effectiveness varied across school types, revealing significant inequities. Teachers in 1AB schools reported high satisfaction due to access to devices, internet connectivity, and trained staff. As one teacher from a 1AB school explained, "*Virtual labs help students visualize concepts that are hard to demonstrate in a physical lab."*

In contrast, teachers from 1C schools expressed mixed opinions, often citing inconsistent resources as a barrier. A 1C teacher noted, "*VLs are useful, but the lack of consistent infrastructure makes it hard to implement effectively."* Type II school teachers overwhelmingly described VLs as unsuitable, primarily due to limited access to infrastructure, such as electricity and computers. One teacher commented, "*Without consistent electricity or computers, virtual labs remain an idea rather than a practice."*

The success of VLs was found to depend heavily on resource availability and teacher training. Teachers across all school types emphasized the need for professional development, with one stating, "*We need more training to integrate virtual labs effectively into our teaching."* The absence of adequate training and resources, particularly in 1C and Type II schools, was frequently cited as a barrier to the effective adoption of VLs.

Furthermore, while VLs were appreciated for their ability to offer safe and interactive environments, they were not seen as replacements for traditional laboratories. Teachers stressed that the tactile, hands-on experiences provided by physical labs remain irreplaceable. As one teacher explained, *"VLs are great for simulations, but students miss the hands-on feel of actual experiments."*

Overall, teachers perceived VLs as valuable tools for fostering student engagement and improving comprehension of complex concepts. However, disparities in infrastructure and training between school types highlighted the challenges of equitable implementation. While 1AB schools are well-positioned to leverage VLs effectively, 1C and Type II schools face significant barriers. Teachers advocated for a blended approach, combining VLs with traditional laboratories to ensure a holistic learning experience.

Challenges faced by Science teachers in urban and rural schools in adopting VLs

Science teachers in both urban and rural schools face significant challenges in adopting VLs. The following tables and paragraphs present the findings of the study.

Quantitative Findings

Table 6

Access to resources (internet and devices) for VLs based on school location

School Location	Reliable Access (Yes)	No Reliable Access
Urban	75%	25%
Rural	35%	65%

The data illustrate a significant disparity in access to resources necessary for implementing VLs between urban and rural schools in Sri Lanka. In urban schools, 75% of teachers reported having reliable access to internet and devices, while 25% lacked such access. In contrast, only 35% of teachers in rural schools indicated reliable access, with 65% reporting a lack of resources. This stark difference highlights the digital divide between urban and rural areas, with rural schools facing greater challenges in adopting VLs for Science education. Addressing these inequities is crucial for ensuring equitable opportunities for all students to benefit from virtual Science education advancements.

Table 7

Challenges faced by teachers in implementing VLs

Challenge	Urban (%)	Rural (%)
Lack of internet connectivity	20%	75%
Insufficient devices	25%	70%
Inadequate technical support	30%	60%
Limited training	35%	65%
Resistance to change	15%	25%

The data highlights the challenges faced by teachers in urban and rural schools when implementing VLs for Science education, with rural teachers experiencing significantly greater difficulties across all categories. Lack of internet connectivity was reported as a major issue by 75% of rural teachers, compared to only 20% of urban teachers, emphasizing the disparity in digital infrastructure. Similarly, insufficient devices were a challenge for 70% of rural teachers, while only 25% of urban teachers faced this issue. Inadequate technical support was reported by 60% of rural teachers and 30% of urban teachers. Limited training was another significant challenge, affecting 65% of rural teachers compared to 35% of urban teachers. Resistance to change, though less frequently reported, was still more prevalent in rural schools (25%) than in urban schools (15%). Overall, the findings reveal that rural teachers encounter compounded challenges, including lack of infrastructure, training, and support, which hinder the effective adoption of VLs.

Table 8

Chi-square test of independence on school location and teachers' challenges in adopting VLs

Test Statistics	Value	df	p-value
Pearson Chi-Square	28.45	1	< 0.001
Likelihood Ratio	28.55	1	< 0.001
Linear-by-Linear Association	27.91	1	< 0.001

A chi-square test of independence was conducted to examine whether there is an association between school location (urban vs. rural) and the challenges faced by teachers in adopting VLs. The test revealed a statistically significant association between the variables, $\chi2$ (1, N=150) =28.45, $p<0.001$. This suggests that school location (urban vs. rural) is significantly related to the challenges faced by teachers, with rural schools experiencing greater challenges than urban schools.

All three test statistics (Pearson, Likelihood Ratio, and Linear-by-Linear Association) yielded statistically significant p-values ($p<0.001$), confirming the association between school location and the challenges faced by teachers in adopting virtual laboratories. The results suggest that rural schools face significantly more challenges than urban schools.

Qualitative Findings

Teachers identified several challenges in adopting and implementing VLs, with disparities between urban and rural schools being particularly prominent. Infrastructure and connectivity issues were among the most significant barriers. Teachers in rural schools frequently cited poor or nonexistent internet connectivity as a major limitation. One rural teacher explained, "*Without a stable internet (connection), it's impossible to even think about using virtual labs.*"

In contrast, urban schools generally had better internet access, though intermittent connectivity issues were reported. An urban teacher noted, "*We can use VLs effectively most of the time, but there are days when connectivity issues make it challenging.*"

Resource limitations also posed challenges, particularly in rural schools. Teachers in these schools highlighted insufficient availability of devices such as computers and tablets. One rural teacher remarked, "*In our school, there's one shared computer for the entire Science classes.*" Urban schools faced fewer issues with device availability but noted challenges with maintaining and upgrading resources to meet the needs of larger classes.

Training gaps were a recurring theme across both urban and rural settings. Teachers emphasized the need for more comprehensive training programmes to effectively use VLs. Rural teachers reported a lack of foundational workshops, with one stating, "*We need hands-on training, not just theory about how virtual labs work.*" Urban teachers, while having access to some training, expressed the need for more advanced workshops to fully integrate VLs into their teaching practices.

Geographic inequalities further exacerbated these challenges. Rural teachers consistently highlighted how their geographic isolation led to unequal distribution of resources and limited access to training opportunities. One teacher observed, "*Urban schools get all the resources and training. We're left to manage on our own."*

In contrast, urban teachers acknowledged their relative advantage, allowing them to explore VLs more effectively. Another critical challenge was the lack of timely technical support and maintenance. Teachers in rural schools, in particular, described long delays in receiving assistance due to their remote locations. One rural teacher shared, *"When something breaks, we wait weeks for someone to come and fix it."* Urban teachers also mentioned the need for immediate technical assistance but experienced shorter delays compared to their rural counterparts.

Overall, teachers across both settings identified infrastructure disparities, resource limitations, insufficient training, and a lack of technical support as key barriers to adopting VLs. Rural schools faced more severe challenges, with teachers emphasizing the need for stable internet, adequate devices, and foundational training programmes.

Relationship between teacher training and the effective use of VLs across school types

The effective use of virtual laboratories across different school types is closely linked to the quality and extent of teacher training. The findings from both quantitative and qualitative analyses are presented as follows.

Quantitative Findings

Table 9

Descriptive statistics on teacher training participation across school types

School Type	Attended Training (%)	Did Not Attend Training (%)
1AB	85%	15%
1C	50%	50%
Type II	30%	70%

Descriptive statistics were used to examine the relationship between teacher training and the effective use of VLs in Science teaching across different school types. The findings revealed notable differences in teacher participation in training programmes across the three school types. In 1AB schools, a significant majority of teachers (85%) reported attending training programmes, while only 15% did not participate. This high participation rate suggests that teachers in 1AB schools are likely receiving ample professional development opportunities, which could positively influence their ability to effectively use VLs in Science instruction. In contrast, 1C schools showed a more balanced distribution, with 50% of teachers attending training and 50%

not attending. This split indicates a potential inconsistency in training opportunities or engagement, which might limit the effectiveness of VLs across these schools. Type II schools, however, showed the most concerning trend, with 70% of teachers reporting that they did not attend any training programmes. This significant gap in professional development opportunities for teachers in Type II schools reflects a critical barrier to the successful integration of VLs in Science teaching. These findings suggest that teacher training is crucial for the effective use of VLs, and schools with lower participation rates in training, particularly Type II schools, may face challenges in effectively implementing these tools in the classroom.

Table 10

Correlation analysis between training sessions and use of VLs

Metric	Correlation Coefficient (r)
Training Sessions vs. Use	0.72

A Pearson correlation analysis was conducted to examine the relationship between the number of training sessions attended by teachers and the frequency with which they applied VLs in their classrooms. The analysis revealed a strong positive correlation ($r=0.72$), indicating that teachers who attended more training sessions were more likely to integrate VLs into their lessons. This suggests that increased professional development is associated with greater adoption and use of VLs in Science teaching.

Qualitative Findings

The relationship between teacher training and the effective use of VLs in Science teaching varied significantly across different school types. Teachers in 1AB schools expressed the need for more advanced, hands-on sessions to enhance their ability to integrate VLs effectively. As one teacher noted, *“We need training that focuses on practical demonstrations rather than just theoretical concepts.”* These schools had access to training opportunities but emphasized the importance of practical application in workshops to ensure effective implementation.

In contrast, teachers from 1C schools reported challenges related to the lack of follow-up support after initial training sessions. While they appreciated the training provided, the absence of ongoing assistance hindered their confidence in using VLs regularly. One teacher explained, “*Training is helpful, but without ongoing support, it’s hard to maintain confidence.”* This indicates that while training sessions were available, they were insufficient to sustain long-term effective use of VLs.

Type II School teachers faced the most significant challenges due to the complete absence of training programmes or professional development opportunities related to VLs. Many teachers in these schools had never attended a workshop or received guidance on how to implement VLs. One teacher stated, “*We haven’t had a single workshop on virtual labs. How can we use them effectively without training?”* This lack of access highlights a critical barrier to the adoption of VLs in these schools.

Overall, teachers who attended more training sessions reported greater confidence and a higher frequency of applying VLs in their teaching. However, significant disparities were evident across school types. Teachers in 1AB schools benefited from more frequent and impactful training programmes, while those in 1C and Type II schools struggled with insufficient opportunities and support. Resource constraints, lack of ongoing support, and inadequate training opportunities emerged as key barriers, particularly for Type II schools.

Perceived impact of VLs on student engagement and learning outcomes across school types and locations

The perceived impact of VLs on student engagement and learning outcomes varies across different school types and locations. The findings from both quantitative and qualitative analyses are presented below.

Quantitative Findings

Table 11

Perceived impact on student engagement by school type

School Type	1	2	3	4	5	Mean Score
1AB	5%	10%	20%	35%	30%	3.8
1C	10%	25%	30%	25%	10%	3.1
Type II	25%	35%	30%	5%	5%	2.4

Descriptive statistics were conducted to assess teachers' perceptions of the impact of VLs on student engagement across different school types. The data were measured on a 5-point Likert scale, where 1 represented "Less Engaged" and 5 represented "More Engaged."

In 1AB schools, the majority of teachers reported that VLs had a positive to very positive impact on student engagement. Specifically, 30% of teachers rated the impact as 5 (More Engaged), and 35% rated it as 4 (Positive Impact), resulting in a mean score of 3.8. This suggests that VL:s are perceived to be highly effective in engaging students in these schools. Teachers in 1C schools showed a more varied perception. While 25% rated the impact as 4 (Positive Impact) and 10% as 5 (More Engaged), a significant portion of teachers (30%) rated the impact as 3 (Neutral), indicating moderate engagement. The mean score for 1C schools was 3.1, which reflects a more balanced but still somewhat favourable view of VLs' impact on student engagement. In contrast, Type II schools reported a much lower perceived impact. The majority of teachers in Type II schools rated student engagement as 1 (Less Engaged) or 2 (Minor Impact), with 25% reporting a 1 (Less Engaged) rating and 35% reporting a 2 (Minor Impact). Only 10% rated the impact as 4 (Positive Impact), and 5% rated it as 5 (More Engaged). The mean score of 2.4 in Type II schools indicates that VLs were perceived as having minimal impact on student engagement.

These findings indicate that the perceived impact of VLs on student engagement is highest in 1AB schools, where teachers report a strong positive effect. In 1C schools, the perception is more neutral, with some positive feedback but also significant variance. The lowest perceived impact was reported in Type II schools, especially in rural areas, where VLs were seen as less effective in engaging students.

Table 12

One-way ANOVA for student engagement across school types

Source of Variation	Sum of Squares	df	Mean Square	F	p-value
Between Groups	54.67	2	27.34	22.18	< 0.001
Within Groups	182.33	147	1.24		
Total	237	149			

A one-way Analysis of Variance (ANOVA) was conducted to examine whether there were significant differences in perceived student engagement across different school types. The results revealed a statistically significant difference between school types, $F(2, 147) = 22.18$, $p < 0.001$, indicating that perceived student engagement significantly varies across the three school types. The between-group sum of squares was 54.67, with 2 degrees of freedom, yielding a mean square of 27.34. The within-group sum of squares was 182.33, with 147 degrees of freedom, yielding a mean square of 1.24. The calculated F-statistic of 22.18 is highly significant, suggesting that the variation between school types is much greater than the variation within school types. The p-value of less than 0.001 further confirms the statistical significance of these differences.

Qualitative Findings

Teachers reported varied perceptions of the impact of VLs on students' engagement and learning outcomes, with significant differences across school types. In 1AB schools, teachers highlighted several positive impacts, emphasizing how VLs help students visualize abstract concepts and conduct experiments that are otherwise impractical in traditional lab settings. One teacher shared, "*Students can explore complex processes, like chemical reactions, in a safe and controlled environment."* While engagement was reported to be high, some teachers noted that deeper learning outcomes often require a combination of virtual and hands-on experiences.

In 1C schools, the perceived impact of VLs was moderate. Teachers acknowledged that VLs served as a useful supplement to traditional methods but required considerable effort to align with their teaching objectives. One teacher explained, "*While virtual labs are a good supplement, students need more guidance to benefit fully."* This suggests that while VLs have potential, their effectiveness in enhancing student learning outcomes depends on additional instructional support.

Teachers in Type II schools reported limited impact, largely due to inadequate infrastructure and resources. Many expressed frustration over the inability to implement VLs effectively, particularly in rural areas. As one teacher lamented, "*Without proper training and resources, virtual labs cannot be effectively used, especially in rural areas."* These challenges have hindered both student engagement and learning outcomes in these schools, highlighting the critical need for targeted resource allocation and training initiatives.

Overall, the perceived impact of VLs on students' engagement and learning outcomes varied by school type and location. Teachers in 1AB schools reported the most positive outcomes, whereas those in 1C and Type II schools faced challenges that limited the effectiveness of VLs. These findings underscore the importance of addressing infrastructural disparities and providing ongoing support to ensure equitable access to the benefits of VLs across all school types.

Conclusion

The study explored the adoption and effectiveness of VLs in Science education across different school types and locations in Sri Lanka, focusing on teacher perceptions, challenges, training, and their impact on student engagement and learning outcomes.

The findings revealed significant differences in teacher perceptions of VLs across school types. Teachers in 1AB schools expressed the most favourable views, citing access to adequate resources and training, while those in 1C schools reported mixed opinions due to inconsistent infrastructure. Teachers in Type II schools demonstrated the least favourable perceptions, primarily due to a lack of technological access and professional development.

Challenges faced by teachers also varied by location. Rural schools encountered more severe barriers, such as unreliable internet connectivity, insufficient devices, and inadequate technical support, compared to urban schools. While urban schools were better equipped, they still faced issues like occasional connectivity problems and the need for advanced technical support.

The study further highlighted the strong relationship between teacher training and the effective use of VLs. Teachers in 1AB schools benefited from frequent training sessions, enabling effective implementation of VLs. In contrast, teachers in 1C and Type II schools, especially in rural areas, struggled with insufficient training opportunities, which limited their ability to integrate VLs into their teaching practices.

Finally, the perceived impact of VLs on student engagement and learning outcomes varied significantly across school types. Teachers in 1AB schools reported high levels of student engagement and learning, while those in 1C schools noted moderate benefits that required additional instructional support. Teachers in Type II schools observed minimal impact, primarily due to resource constraints and infrastructural challenges.

Recommendations

To address the disparities and challenges identified in the study, several actionable suggestions are proposed. First, improving infrastructure and digital access is critical, particularly for rural and Type II schools. Policies should focus on enhancing internet connectivity and ensuring equitable access to devices such as computers and tablets. National-level initiatives could play a pivotal role in bridging the digital divide and providing the necessary technological resources to underprivileged schools.

Comprehensive and ongoing teacher training is essential for the effective use of VLs. Training programmes should be customized to address the specific needs of teachers in different school types. Advanced workshops can be designed for 1AB schools, while foundational training should target teachers in Type II schools. Moreover, follow-up training sessions and the establishment of online support systems would provide teachers with continuous guidance, thereby increasing their confidence and competence in using VLs.

A blended learning approach should be adopted to maximize the benefits of VLs. Combining virtual and traditional laboratory methods can offer students both tactile, hands-on experiences and the flexibility of simulations. Aligning VL activities with the Nnational Science Curriculum will further ensure their relevance and effectiveness in complementing existing teaching methods.
Strengthening technical support systems is another priority. Regional technical centres could provide timely assistance for maintenance and troubleshooting, especially in rural areas where delays are more pronounced. Additionally, regular updates and maintenance of devices and software are crucial for sustaining the functionality and effectiveness of VLs.

Equitable access to VLs requires targeted policy interventions. Resource allocation should prioritize schools facing the most significant barriers, particularly those in rural areas. Monitoring and evaluation systems should be established to track the impact of these interventions, ensuring accountability and facilitating continuous improvement.

Finally, fostering research and development is essential for sustaining progress in integrating VLs. Pilot projects can test innovative approaches in resource-constrained environments, while longitudinal studies could assess the long-term impact of VLs on student engagement and learning outcomes. These efforts would provide valuable insights for refining strategies and ensuring the sustainable integration of VLs in Sri Lankan schools.

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