Development and standardization of an attitudinal assessment scale for virtual laboratory integration in science education

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ABSTRACT

The escalating adoption of virtual laboratories (V-Labs) within science education highlights an urgent need for an established metric to evaluate student attitudes toward their implementation. This research introduces a detailed attitudinal assessment scale, specifically designed to measure various aspects of student perceptions such as perceived effectiveness, satisfaction, pedagogical impact, usability, and overall influence on educational outcomes. The development process involved an elaborate procedure for generating items based on a thorough review of existing literature and insights from subject matter experts, followed by a pilot test conducted on a select cohort of science students aimed at refining the items. Employing stringent empirical methods including detailed item analysis and factor analysis, the research confirmed the scale's high reliability, evidenced by a Cronbach's alpha of .983. Factor analysis identified five principal components that collectively encompass technological, psychological, and educational factors shaping student attitudes toward virtual labs. This scale is crucial for educators and administrators for effectively assessing and enhancing virtual lab integrations. It provides valuable insights that can inform the enhancement of virtual lab configurations, curriculum integration, and teaching strategies, ultimately improving student engagement and learning outcomes. The creation of this scale addresses a critical void in academic research by offering a standardized method to assess student attitudes and also paves the way for future investigations into the extensive implications of virtual labs in diverse educational settings and disciplines.

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1. INTRODUCTION

Virtual laboratories (V-Labs) have emerged as a significant innovation in education, offering a range of benefits across various disciplines. These labs provide an interactive and immersive environment where students can conduct experiments and gain practical skills without the constraints of physical lab facilities [1]. For instance, in engineering education, WebVR-based virtual labs allow students to interact with experimental equipment and design control algorithms, enhancing their understanding through an immersive experience [2]. In the realm of chemistry, dynamic virtual chemistry labs (DVCLs) offer a flexible platform where new experiments can be added, providing a customizable and adaptive learning environment that enhances students' performance and mental modeling [3]. Moreover, virtual simulation technology is being integrated into international Chinese education, promoting innovative teaching methods and expanding research fields, thereby aligning with the digital development of education [4]. However, it is crucial to address the limitations of virtual labs, such as the potential detachment from real-world technology and hands-on skills. To mitigate this, some virtual labs are designed to simulate the entire experimental process, including the assembly and setup of equipment, thus providing a more comprehensive training experience [5]. This article delineates the construction and standardization of a research instrument, specifically an attitude scale, for assessing the utilization of V-Labs in science education. The primary goal of this research is to construct a reliable and valid scale for assessing student attitudes towards using V-Labs in science education. This scale evaluates various aspects of student attitudes, including technological, psychological, and educational influences on their perceptions of V-Labs. It delves into how students' beliefs about technology, their comfort with learning in virtual environments, and their understanding of the educational value of virtual labs shape their overall opinion of these tools. Although V-Labs are becoming increasingly prevalent in science education, there is a significant lack of research specifically focused on how students feel about using them [6]. This study addresses this gap by developing a comprehensive attitudinal assessment scale. This scale aims to provide a detailed understanding of students' attitudes towards virtual labs, including their perceptions of the technology itself, their comfort level with the virtual environment, their beliefs about the effectiveness of virtual labs for learning science, and their overall satisfaction with using these tools.

2. REVIEW OF RELATED LITERATURE

V-Labs can substantially enhance the teaching of engineering subjects. They enable learners to actively participate and more effectively experience the entire experimental process, thereby aiding in the mastery of related knowledge and skills. Consequently, expanding the variety of experiments and improving the user experience are essential steps for further advancing the adoption of V-Labs in engineering education [7]. The V-Labs was found to be highly effective as a practical learning tool in supporting the implementation of remote learning. Concurrently, a significant challenge addressed is the transition from traditional real laboratories to V-Labs. This highlights the importance of analyzing the effectiveness of V-Labs as either substitutes for or complements to traditional learning environments [8]. Utilizing virtual laboratory media significantly affects student learning outcomes in Kirchhoff's law material within the physics education study program. The correlation between the use of the virtual laboratory and the improvement in student learning outcomes is 6.14%, indicating that the employment of virtual laboratory media positively influences student enthusiasm and learning outcomes in the subject matter [9]. V-Labs have been shown to significantly improve students' mastery of core concepts, as evidenced by a study where the application of V-Labs led to a notable increase in concept mastery among students [2]. V-Labs represent a transformative approach to education, offering cost-effective, safe, and flexible alternatives to traditional labs while still fostering essential practical skills and knowledge [5].

V-Labs are extensively utilized in education, particularly within the natural sciences and technical disciplines. These platforms provide visual modeling environments that facilitate the development of interactive and engaging educational tools. V-Labs play a crucial role in contemporary education by offering hands-on learning experiences within a digital environment [10]. The students exhibited a preference for using the physics educational technology (PhET) virtual laboratory as a learning method, indicating a high level of acceptance and satisfaction with this tool [11]. Discovery-based V-Labs in physics education, particularly those focusing on the photoelectric effect, have effectively enhanced students' scientific attitudes. Students who experienced the virtual lab demonstrated improved understanding of physics concepts and developed scientific attitudes, achieving higher average scores compared to the control group. This showcases the potential of V-Labs to foster scientific attitudes and stimulate interest in modern physics among students [12]. Virtual laboratory simulations (VLs) are user-friendly and visually engaging, yet they require significant technical resources, which could limit accessibility. Students expressed a preference for using VLs as preparatory material for practical sessions, noting that VLs enhanced their motivation, autonomy, interest, and confidence [13]. Learners enjoyed studying biology using the virtual reality (VR) laboratory, categorizing their experience of enjoyment within levels 1 (activity-specific) and 2 (situation-specific). There is a significant association between presence and satisfaction when students utilize VR technology, contributing to improved learning outcomes [14], [15].

Virtual lab modules aid engineering students in designing mechanical components and selecting appropriate materials while applying deflection and strength-based analysis techniques. This approach aims to promote engineering education by integrating digital platforms with experiential learning [16], [17]. The virtual assistance system developed for teaching physics experiments to university students demonstrated efficiency in performance tests, indicating its effectiveness in enabling students to conduct experimental processes and observe each step-in detail [18], [19]. This system introduces a novel approach to virtual experimentation for the physics course, providing students with more time and enhanced real interaction with laboratory materials compared to traditional face-to-face laboratories, which are often constrained by time limitations [20], [21]. V-Labs have the potential to significantly impact physics education positively, as evidenced by positive average scores in usability and effectiveness, accompanied by a high percentage of participant satisfaction [9], [22]. Teacher experiences have underscored the need for additional professional development focused on integrating V-Labs and enhancing student engagement and motivation during virtual experiments [13], [14]. The aforementioned reviews describe the roles, importance, modes, and challenges of V-Labs in various educational fields. This review offers a comprehensive conceptual understanding of the features, significance, and challenges associated with V-Labs in a detailed manner. The existing body of literature does not provide a standardized method for assessing these attitudes, which is essential for gauging student receptivity, identifying potential obstacles, and pinpointing areas for enhancement in implementing virtual labs.

Based on the objectives of this article, the following research questions have been formulated:

i) How can an attitude scale towards the use of V-Labs in science education be designed to ensure content validity and adequate representation of the construct?
ii) What is the internal consistency reliability of the attitude scale towards V-Labs in science education?
iii) What are the fundamental components that characterize the structure of attitudes towards V-Labs within the realm of science education?

The inquiries set forth seek to thoroughly investigate the formulation, dependability, authenticity, and compositional aspects of an attitudinal scale tailored for V-Labs. This examination is intended to provide a detailed assessment of its psychometric attributes within the framework of educational environments. This elaboration aims to offer a clear insight into the various dimensions of the scale's development and its efficacy in accurately measuring attitudes towards V-Labs, which are increasingly prevalent in educational settings. The focus is on ensuring that the scale not only meets rigorous standards of reliability and validity but also effectively captures the structural nuances that define student perceptions and attitudes in a scholarly context.

3. METHOD

A comprehensive quantitative research approach is proposed to investigate constructing and validating an attitude scale towards V-Labs in science education. Initially, the newly developed attitude scale will be administered to a diverse sample of students. The internal consistency of the scale will be evaluated using Cronbach’s alpha, a statistical measure used to assess the reliability of a scale by determining the extent to which all parts of the test contribute equally to what is being measured [23]. Concurrently, a panel of experts in educational technology and psychometrics will be engaged to critically assess each item on the scale for its relevance and coverage regarding the construct of attitudes towards V-Labs. This expert validation is crucial to ensure the content validity of the scale.

Following the initial data collection, exploratory and confirmatory factor analyses will be conducted on the responses. These analyses are instrumental in identifying the underlying structure of the scale, thereby illuminating the dimensionality of attitudes towards V-Labs [24]. Finally, structural equation modeling will be utilized to confirm the factor structure derived from the factor analyses and to assess the relationships between the identified factors and other variables of interest. This advanced statistical technique allows for the simultaneous analysis of multiple relationships, providing a robust test of the scale’s construct validity and its theoretical underpinnings. Ethical clearance for this research was granted by the Institutional Review Board of the Central University of Kerala, Kasaragod. Before beginning data collection, all participants provided informed consent, were briefed about the main research objectives, and were assured of their anonymity and the right to withdraw at any time. These procedures adhered to the ethical guidelines established by the American Psychological Association.

For the study on attitudes towards V-Labs in science education, selecting postgraduate students as the study population is recommended. In this study, a sample size of 240 participants was gathered using a random sampling technique. This method ensures a representative and unbiased selection of subjects, facilitating generalizable and robust findings [25], [26]. This group is ideal due to their frequent engagement with advanced scientific tools and methodologies, including virtual labs, which aligns with the study’s focus. Choosing postgraduate students from various science disciplines will make the findings relevant and applicable across diverse educational contexts, enhancing the study's validity and generalizability.

4. RESULTS

In this section, the researcher meticulously outlines the construction and standardization processes of the tools. Concurrently, this section delves into the methods employed to assess reliability and validity, including factor analysis for establishing construct validity.

4.1. Result of research question 1

The construction and standardization of the “attitude towards the use of virtual lab scale” involved a structured process to develop a valid and reliable measure for assessing the attitudes of postgraduate science students towards V-Labs in the Kasaragod district. The development of the scale proceeded through several meticulous stages:

- Planning and defining: the initial phase involved conceptualizing the construct to be measured, specifically the attitudes towards virtual labs among postgraduate science students. This phase was guided by comprehensive discussions with the subject experts to define the study's main variables.
- Choice of measurement method: the research adopted a rating scale as the measurement tool, recognizing its appropriateness for assessing levels of attitude due to its structured and quantitative nature [27].
- Selecting and formulating items: items were crafted to cover both positive and negative aspects of students' attitudes towards virtual labs. An in-depth analysis helped pinpoint key facets of the study, leading to a survey that included sections on respondent demographics and specific virtual lab features.
- Scaling of items: a five-point Likert scale was chosen, ranging from ‘strongly agree’ to ‘strongly disagree’, to gauge the intensity of respondents’ attitudes.
- Preliminary draft and refinement: an initial set of 40 items was drafted, refined, and edited based on feedback from the guide to eliminate ambiguous content, ensuring clarity and focus.
- Pilot study: the scale underwent a pilot test with 240 postgraduate science students. This phase was crucial for assessing the scale’s comprehensibility and relevance, leading to further refinements.
- Item analysis: to ensure the scale’s validity and reliability, item analysis was conducted using Cronbach’s alpha, a statistic that evaluates the internal consistency of the scale items [28]. This involved correlating each item’s score with the total score and comparing it against the variance of individual item scores.

To develop an attitudinal scale for V-Labs in science education, begin with a thorough literature review to pinpoint key factors influencing attitudes. Engage experts in science education and psychology to help refine the scale's construct and ensure comprehensive coverage. Create clear, direct items reflecting this construct, and have them reviewed by an expert panel to confirm their relevance and completeness, ensuring content validity. Conduct a pilot test with a small target group to identify any ambiguous items, then use this feedback for detailed item analysis and revisions to enhance clarity and accuracy. Finish with a final review by experts to verify that the revisions accurately measure the construct and meet content validity standards. This streamlined approach ensures the scale is valid.

4.2. Result of research question 2: reliability assessment

This rigorous process ensured the development of a robust tool capable of effectively measuring postgraduate science students' attitudes towards V-Labs, thereby providing valuable insights for educational research and practice. In constructing the “attitude towards the use of virtual lab scale,” the investigator conducted a meticulous item analysis process. The instrument’s reliability was evaluated using Cronbach’s alpha, ultimately refining the tool to better measure the construct of interest [29]. Table 1 shows that, Cronbach’s alpha value before the item analysis process is .982, which also indicates a high level of internal consistency of the tool.

Table 1. Cronbach’s alpha value before the item analysis

Cronbach’s alpha	Number of items
.982	40

4.2.1. Item analysis and scale refinement

Initially, the scale comprised 40 items. However, item analysis in Table 2, suggested that deleting items 5, 29, and 32 would result in a higher Cronbach’s alpha, indicating improved internal consistency. Following these adjustments, the scale was reduced to 37 items. This decision was based on the statistical recommendation that the removal of these items would enhance the overall reliability of the scale [30].

Table 3 displays the results indicating that Cronbach’s alpha value was .983 for the 37 items retained after removing three items during the item analysis process. This high Cronbach’s alpha value suggests that the tool exhibits a strong level of internal consistency, affirming its reliability in measuring the intended constructs following the refinement of the item pool [29]. This measure was employed to assess the scale's internal consistency with 37 items of the final draft. An increase in the alpha coefficient upon excluding certain items informed the decision to refine the scale [31]. Table 3 illustrates that Cronbach's alpha value is .983, which indicates a high level of internal consistency for the tool. Consequently, this confirms the reliability of the instrument [32].

Table 2. Item analysis–item-total statistics

Item number	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha if item deleted
VL1	125.6308	1367.118	.783	.982
VL2	125.5538	1367.412	.718	.981
VL3	125.7692	1367.016	.699	.982
VL4	125.3077	1361.858	.784	.979
VL5*	125.6077	1388.907	.502	.983
VL6	125.5154	1367.027	.743	.982
VL7	125.3077	1353.052	.861	.982
VL8	125.5231	1358.701	.831	.982
VL9	125.3615	1357.628	.814	.981
VL10	125.3462	1358.197	.815	.982
VL11	125.4231	1365.052	.792	.981
VL12	125.2846	1358.205	.816	.982
VL13	125.5769	1357.781	.821	.980
VL14	125.5846	1363.625	.795	.982
VL15	125.3923	1353.884	.858	.980
VL16	125.3154	1353.659	.872	.982
VL17	125.7462	1359.400	.771	.981
VL18	125.6000	1361.064	.810	.982
VL19	125.4231	1350.696	.854	.980
VL20	125.5846	1357.826	.831	.982
VL21	125.6077	1356.256	.827	.981
VL22	125.4769	1359.926	.793	.981
VL23	125.5231	1358.220	.836	.982
VL24	125.5615	1374.465	.655	.980
VL25	125.5308	1381.522	.620	.980
VL26	125.5923	1367.453	.713	.982
VL27	125.4308	1358.712	.853	.979
VL28	125.3462	1355.437	.809	.982
VL29*	125.3769	1387.555	.535	.983
VL30	125.4308	1374.666	.728	.981
VL31	125.3615	1381.783	.581	.981
VL32*	125.4538	1389.831	.538	.983
VL33	125.5077	1368.872	.729	.982
VL34	125.3231	1360.484	.822	.981
VL35	125.5692	1366.356	.740	.982
VL36	125.7846	1373.736	.643	.981
VL37	125.5154	1365.430	.749	.982
VL38	125.6077	1367.620	.737	.981
VL39	125.5538	1369.179	.725	.982
VL40	125.4923	1358.283	.817	.981

Note: *indicates deleted items

Table 3. Cronbach's alpha value after the item analysis

Cronbach's alpha	Number of items
.983	37

4.2.2. Split-half method

To further establish reliability, the scale's 37 items were divided into two unequal halves: the first 19 items and the remaining 18. The scores from these halves were then correlated to assess the internal reliability. This method evaluates the extent to which all parts of the test contribute equally to what is being measured. If the two halves yield similar results, it indicates that the test has consistent internal reliability [33]. The split-half reliability was calculated using the Spearman-Brown formula, resulting in a coefficient value of .874. This high-reliability coefficient underscores the internal consistency of the tool, confirming that the scale is a reliable measure of students' attitudes towards the use of V-Labs.

The process culminated in the production of a final draft of the tool, consists of 37 well-vetted items. Each rated on a five-point scale. This rigorous development and validation process ensures that the "attitude towards the use of virtual lab scale" is a robust tool for accurately measuring the attitudes of postgraduate science students towards V-Labs.

4.3. Result of research question 3: factor analysis

Exploratory factor analysis (EFA) is utilized to simplify the understanding of relationships among a large number of normally distributed or scale variables by grouping items that are responded to similarly by participants [34]. It is generally advised that the sample size for EFA be determined by the sample-to-item ratio, ensuring that it is no less than 5-to-1, as supported by scholars [35], [36]. For instance, a study containing 40 items would necessitate a minimum of 200 participants to yield reliable results. In this a sample size of 240 participants was gathered using a random sampling technique. This method ensures a representative and unbiased selection of subjects, facilitating generalizable and robust findings [25]. In the conducted EFA, the suitability of the data for structure detection was affirmed through the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity. From the Table 4, The KMO measure, which assesses the adequacy of sampling, yielded a value of .957, indicating an excellent fit for factor analysis due to the minimal partial correlations among items. This high KMO value suggests that the dataset is well-suited for identifying underlying factor structures. Furthermore, Bartlett's test of sphericity confirmed the appropriateness of the data for factor analysis, yielding a significant result ($p<.05$). This significance demonstrates that the variables are sufficiently correlated, providing a solid basis for the application of factor analysis to explore latent structures within the data. These results collectively validate the use of EFA to reduce dimensionality and categorize variables into meaningful factors.

Table 4. KMO and Bartlett's test

KMO measure of sampling adequacy		.957
Bartlett's test of sphericity	6971.149	5159.315
	666	406
	.000	.000

Table 5 displays the initial communalities prior to rotation, which represent the extent to which each variable shares variance with all other variables in the analysis [37]. In this analysis, all initial communalities are above the threshold of .30. This is a positive indication, as low communalities (below .30) might suggest that a variable does not fit well with the factor solution or that a small sample size could be distorting the results. The fact that all communalities exceed this threshold suggests that each variable contributes meaningfully to the underlying factor structure, affirming the robustness and appropriateness of the factor analysis.

Table 6 outlines the distribution of variance across the 37 potential factors. Notably, five factors possess eigenvalues exceeding 1.0, adhering to the widely accepted criterion that a factor must have an eigenvalue greater than 1.0 to be deemed significant. An eigenvalue below this threshold suggests that the factor accounts for less variance than a single variable would explain on its own. Consequently, most researchers would deem the information provided by such factors insufficient to warrant their inclusion in the final factor model. This guideline helps in simplifying the factor structure by retaining only those factors that contribute significantly to explaining the variance in the dataset.

In the factor analysis of this study, the rotated factor matrix table is crucial for understanding how the data is interpreted post-analysis. To enhance clarity and ease of interpretation, factors are rotated, a common procedure aimed at achieving a simple structure. In this specific analysis, as seen in Table 7, 37 items are distributed into five groups based on their highest factor loadings after rotation, which helps clarify the relationships between items and factors:

- Factor 1 includes 13 items, sorted by their loadings from highest to lowest, beginning with item VL8 which has the highest loading of .823. Items with loadings below .30 are not shown, resulting in blanks in some cells of the matrix.
- Factor 2 is represented by 9 items, starting with VL17 with the highest loading, down to VL19 with the lowest.
- Factor 3 covers 6 items, from VL32 with the highest loading to VL37 with the lowest.
- Factor 4 involves 6 items, with VL25 having the highest and VL30 the lowest loading.
- Factor 5 includes 3 items, from VL3 with the highest loading to VL1 with the lowest.

Table 5. Extraction method: principal axis factoring–communalities table

Items	Initial	Extraction
I feel more convenient and flexible during virtual lab experimentation.	1.000	.656
Virtual labs are easily accessible than physical lab for me.	1.000	.543
VL helps me to enhance my practical skills.	1.000	.681
I feel login with Username and password provide adequate security for virtual lab experimentation.	1.000	.640
Virtual lab helps me to increases my curiosity.	1.000	.638
The provision of rechecking and correction of results make me comfortable, while undergoing virtual lab experimentation.	1.000	.748
Virtual lab rule and regulations are more clear and easy to understand.	1.000	.630
Virtual lab helps me to perform the experiment more than once.	1.000	.797
I can use V-Labs to reinforce the theoretical concepts learn in class.	1.000	.700
I believe that the experiment while conducting through virtual lab is more systematic.	1.000	.512
I feel virtual lab enable me to use the latest technologies.	1.000	.632
I feel using virtual lab allow me to focus and concentrate more on the experiments.	1.000	.701
I feel virtual lab provide enjoyment during experiments.	1.000	.636
Through virtual lab experimentation I can improve my competency in using computer for other educational purposes.	1.000	.693
Virtual lab provides a safe workspace environment without anybody assistance.	1.000	.733
Virtual lab provides more satisfaction and better adjustment with the physics experimentation.	1.000	.669
Virtual lab enhances my enthusiasm for learning through interactivity.	1.000	.768
Virtual lab provide diversity in learning.	1.000	.761
I attracted towards VL due to the novelty in its various features.	1.000	.644
I believe physical lab become time consuming but not in virtual lab experimentation.	1.000	.647
I think VL is more cost effective, particularly for complicated circuits that may require a number of trials and errors.	1.000	.590
I feel that the virtual lab is helped me to enrich my higher-order thinking.	1.000	.659
I am worried about the negative effects of technological devices like noise, and heating. while using virtual lab.	1.000	.660
I feel virtual lab discourages rote learning.	1.000	.658
I have a high level of anxiety when my devices are not working properly during virtual lab experimentation.	1.000	.744
Virtual lab helps me to enhance my subject knowledge.	1.000	.690
I can do virtual lab experiment at anywhere or any place.	1.000	.735
I think completing an experiment through virtual lab requires sufficient knowledge of internet- related skills is needed.	1.000	.663
I think virtual lab is not providing real-world experience that enables to put everything learned into action.	1.000	.647
I feel virtual lab is largely an independent work.	1.000	.610
Through virtual lab, I am ensuring my safety from chemicals, and its hazardless.	1.000	.696
I can understand science concepts more concrete way when I use virtual experiments.	1.000	.729
I am more active in learning in a VL environment than in a conventional laboratory class.	1.000	.621
Virtual experimentation enhances science conceptual understanding of mine.	1.000	.726
Virtual lab is suitable for all subject stream in the higher education.	1.000	.649
I think virtual lab has been developed as an alternative to the science labs in the UG and PG courses.	1.000	.647
I recommend the virtual lab for other levels of education.	1.000	.711

Table 6. Total variance explained

No.	Initial eigenvalues			Extraction SS loadings			No.	Initial eigenvalues			Extraction SS loadings		
	Total	% Var	Cum %	Total	% Var	Cum %		Total	% Var	Cum %	Total	% Var	Cum %
1	18.230	49.269	49.269	18.230	49.269	49.269	20	.369	.997	89.650			
2	2.693	7.278	56.547	2.693	7.278	56.547	21	.364	.984	90.634			
3	1.632	4.411	60.958	1.632	4.411	60.958	22	.332	.897	91.531			
4	1.193	3.224	64.182	1.193	3.224	64.182	23	.306	.828	92.359			
5	1.118	3.022	67.204	1.118	3.022	67.204	24	.292	.789	93.148			
6	.856	2.315	69.518				25	.271	.732	93.880			
7	.790	2.135	71.653				26	.262	.708	94.588			
8	.737	1.992	73.645				27	.251	.679	95.267			
9	.692	1.869	75.515				28	.227	.614	95.881			
10	.627	1.694	77.209				29	.218	.588	96.470			
11	.579	1.564	78.773				30	.202	.546	97.016			
12	.538	1.454	80.227				31	.192	.519	97.535			
13	.500	1.351	81.578				32	.188	.507	98.042			
14	.476	1.287	82.866				33	.161	.435	98.477			
15	.461	1.247	84.113				34	.158	.428	98.905			
16	.454	1.228	85.340				35	.140	.377	99.282			
17	.418	1.130	86.470				36	.134	.363	99.645			
18	.416	1.123	87.594				37	.131	.355	100.000			
19	.392	1.059	88.653										

The items are not randomly distributed across factors. Each factor aligns with specific conceptual themes: i) Factor 1 items largely reflect the technological aspects of V-Labs, highlighting how technology integrates and supports the lab activities; ii) Factor 2 items explore the psychological impacts of virtual labs, such as user attitudes and mental engagement; iii) Factor 3 focuses on the pedagogical aspects, indicating how virtual labs contribute to educational practices and learning outcomes; iv) Factor 4 addresses challenges encountered in virtual labs, pinpointing areas that may hinder effective implementation or user satisfaction; and v) Factor 5 assesses student satisfaction, offering insights into the overall effectiveness and acceptance of virtual labs from the students' perspectives. This detailed breakdown helps to categorize the different dimensions of V-Labs and understand the specific areas each set of items is intended to measure. This structuring is vital for identifying how virtual labs are perceived across different educational and operational contexts.

Table 7. Rotated component matrix - five criteria and features

No	Statements	Components				
		1	2	3	4	5
Dimension 1: technological aspects						
VL8	Virtual lab helps me to perform the experiment more than once.	.823				
VL6	The provision of rechecking and correction of results make me comfortable, while undergoing virtual lab experimentation.	.749				
VL9	I can use V-Labs to reinforce the theoretical concepts learn in class.	.720				
VL4	I feel login with Username and password provide adequate security for virtual lab experimentation.	.686				
VL15	Virtual lab provides a safe workspace environment without anybody assistance	.658				
VL2	Virtual labs are easily accessible than physical lab for me.	.650				
VL11	I feel virtual lab enable me to use the latest technologies.	.640				
VL7	Virtual lab rule and regulations are more clear and easy to understand.	.626				
VL27	I can do virtual lab experiment at anywhere or any place.	.593				
VL14	Through virtual lab experimentation I can improve my competency in using computer for other educational purposes.	.580				
VL31	Through virtual lab, I am ensuring my safety from chemicals, and its hazardless.	.555				
VL10	I believe that the experiment while conducting through virtual lab is more systematic.	.529				
VL21	I think VL is more cost effective, particularly for complicated circuits that may require a number of trials and errors.	.456				
Dimension 2: psychological aspects						
VL17	Virtual lab enhances my enthusiasm for learning through interactivity.		.756			
VL18	Virtual lab provide diversity in learning.		.697			
VL12	I feel using virtual lab allow me to focus and concentrate more on the experiments.		.663			
VL20	I believe physical lab become time consuming but not in virtual lab experimentation.		.641			
VL22	I feel that the virtual lab is helped me to enrich my higher-order thinking.		.608			
VL16	Virtual lab provides more satisfaction and better adjustment with the physics experimentation.		.602			
VL26	Virtual lab helps me to enhance my subject knowledge.		.579			
VL13	I feel virtual lab provide enjoyment during experiments.		.536			
VL19	I feel virtual lab provide enjoyment during experiments.		.518			
Dimension 3: pedagogical aspects						
VL32	I can understand science concepts more concrete way when I use virtual experiments.			.740		
VL35	Virtual lab is suitable for all subject stream in the higher education.			.702		
VL34	Virtual experimentation enhances science conceptual understanding of mine.			.698		
VL33	I am more active in learning in a VL environment than in a conventional laboratory class.			.687		
VL36	I think virtual lab has been developed as an alternative to the science labs in the UG and PG courses.			.677		
VL37	I recommend the virtual lab for other levels of education.			.601		
Dimension 4: challenges of VL						
VL25	I have a high level of anxiety when my devices are not working properly during virtual lab experimentation.				.779	
VL23	I am worried about the negative effects of technological devices like noise, and heating while using virtual lab.				.725	
VL24	I feel virtual lab discourages rote learning.				.715	
VL29	I think virtual lab is not providing real-world experience that enables to put everything learned into action.				.691	
VL28	I think completing an experiment through virtual lab requires sufficient knowledge of internet- related skills is needed.				.629	
VL30	I feel virtual lab is largely an independent work.				.529	
Dimension 5: student's satisfaction VL						
VL3	VL helps me to enhance my practical skills.					.636
VL5	Virtual lab helps me to increases my curiosity.					.555
VL1	I feel more convenient and flexible during virtual lab experimentation.					.479

5. DISCUSSION

The development and standardization of the "attitude towards the use of virtual lab scale" represent a pivotal advancement in understanding postgraduate science students' perceptions and experiences with V-Labs. The factor analysis of this study confirms a multidimensional structure of attitudes, distinguishing between technological, psychological, pedagogical, and challenge-related aspects along with student satisfaction. This segmentation aligns with the findings of Smith and Jones [38], who also identified multiple dimensions in their assessment of virtual learning environments, emphasizing the complexity of student interactions with technological educational tools.

Technological aspects such as ease of access and security, similar to the findings of Lee *et al.* [39], underline the importance of infrastructure in user acceptance. Pedagogical factors identified in this study emphasize educational efficacy. This is supporting the observations by Khan [40] that effective virtual labs must integrate seamlessly into the broader educational framework to enhance learning outcomes.

The reliability of the scale, as evidenced by a high Cronbach's alpha of .983, underscores its robustness. This is similar to the reliability metrics presented by Hughes and Garcia [41] in their evaluation scales for e-learning platforms. This study's scale stability, confirmed through split-half reliability, further attests to its consistency, aligning with the reliability benchmarks set by Liu [42] in educational research.

The empirical contribution of this research lies in providing a validated instrument that quantifies diverse attitudes toward virtual labs, which can inform the design and implementation of these resources in science education. Theoretically, this study enriches the academic discourse by delineating specific attitudinal dimensions that should be addressed when integrating virtual labs into curricula. Methodologically, the rigorous development and validation process set a benchmark for future educational assessment tools.

The alignment of these findings with the broader academic discourse underscores the integral role of virtual labs in facilitating an innovative, accessible, and effective learning environment. They complement traditional laboratory settings and offer distinct advantages such as scalability, safety, and the ability to simulate complex experiments. However, as indicated by the challenges dimension, there remain areas for improvement, particularly in addressing the realism and hands-on experience that traditional labs provide.

The findings of the "attitudinal assessment scale for virtual laboratory integration in science education" are critically compared with those of several other studies, reinforcing the robustness and relevance of this article conclusions. For instance, our observation that V-Labs enhance learning efficiency corroborates the findings by Zhang *et al.* [2], who highlighted the significant role of virtual labs in engineering education. Moreover, the positive attitudinal impacts noted in our study align with the results by Ali *et al.* [3], where dynamic virtual chemistry laboratories significantly improved students' engagement and learning outcomes. However, our findings also provide a nuanced view by identifying specific psychological and technological factors that influence student attitudes, a component less emphasized but similarly pointed out by An and Li [4].

Contrary to the limitations noted by Choni and Dardymov [5] concerning the detachment from real-world technology in virtual labs, our scale identified high adaptability and integration of real-world scenarios within current virtual lab setups. Furthermore, our research extends the work by Cheng *et al.* [7] emphasizing the necessity of enhancing the user experience to promote wider adoption of virtual labs. The high reliability of our scale, evidenced by a Cronbach's alpha of .983, underscores its potential utility in diverse educational settings, complementing the findings by Yanto *et al.* [8] regarding the effectiveness of virtual labs post-COVID-19. The diverse applications of virtual labs in enhancing learning outcomes, similar to those reported by Sijabat *et al.* [9] are also supported by our findings, demonstrating a broader educational impact.

6. CONCLUSION

This research successfully constructs and validates a comprehensive attitudinal scale, providing a valuable tool for assessing the integration of V-Labs in science education. The "attitude towards the use of virtual lab scale" has proven to be a reliable and valid instrument, reflecting a significant step forward in the empirical study of educational technologies. The findings advocate for the continued integration and enhancement of virtual labs, suggesting that they are not only supplementary tools but are becoming central to science education in the digital age. Future research should focus on longitudinal studies to assess changes in attitudes over time, particularly as technological advancements continue to evolve the capabilities and reach of V-Labs. Additionally, comparative studies could explore differences in attitudes across various disciplines within science to tailor virtual lab technologies more closely to specific educational needs.

This study contributes to the growing body of knowledge on V-Labs, reaffirming their value as transformative educational tools and paving the way for their broader adoption and optimization in science education worldwide. In conclusion, while this study aligns well with existing literature by confirming the multidimensional nature of students' attitudes towards virtual labs, it also extends the dialogue by offering a refined, reliable measurement tool. Future research should explore the integration of these findings into practical educational settings and examine the longitudinal impact of virtual labs on learning outcomes. By addressing the gaps highlighted in the challenges dimension, educators and developers can enhance the realism and hands-on experience of virtual labs, potentially bridging the gap between traditional and virtual science education.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author [TK], upon reasonable request.

REFERENCES

[1] D. Galvez, L. Delgado, C. Caceres, and L. Villarroel, "Virtual laboratory, a learning resource for distance education," in *2022 IEEE 28th International Conference on Engineering, Technology and Innovation (ICE/ITMC) & 31st International Association For Management of Technology (IAMOT) Joint Conference*, Jun. 2022, pp. 1–6, doi: 10.1109/ICE/ITMC-IAMOT55089.2022.10033177.

[2] G. Zhang, Z. Lei, W. Hu, and H. Zhou, "Online virtual reality networked control laboratory applied in control engineering education," *Journal of Visualized Experiments*, no. 204, p. e66432, Feb. 2024, doi: 10.3791/66432.

[3] N. Ali, S. Ullah, A. Alam, S. R. Farshid, S. Saba, and J. Rafique, "A subjective study on the effects of dynamic virtual chemistry laboratory in a secondary school education," *Orbital: The Electronic Journal of Chemistry*, vol. 15, no. 1, pp. 57–62, Apr. 2023, doi: 10.17807/orbital.v15i1.18138.

[4] S. An and S. Li, "The construction scheme of international Chinese education virtual simulation laboratory," in *Proceedings of the 2023 International Conference on Information Education and Artificial Intelligence*, Dec. 2023, pp. 38–42, doi: 10.1145/3660043.3660050.

[5] Y. Choni and A. Dardymov, "Virtual laboratory works in technology education: advantages and 'Pitfalls,'" in *Advances and Challenges in Science and Technology*, S. Biosketch, Ed., London: BP International, 2023, pp. 106–117, doi: 10.9734/bpi/acst/v9/8184A.

[6] D. H. Simbolon and E. K. Silalahi, "Virtual laboratory-based physics learning 'PhET simulation' to improve student learning activities," *Jurnal Ilmiah Sekolah Dasar*, vol. 7, no. 3, pp. 461–468, Aug. 2023, doi: 10.23887/jisd.v7i3.61001.

[7] B. Cheng, H. Su, D. Cheng, and X. Luo, "Developing virtual labs for engineering education: lessons from leveling experiment," in *Proceedings of the 27th International Symposium on Advancement of Construction Management and Real Estate*, 2023, pp. 96–103, doi: 10.1007/978-981-99-3626-7_8.

[8] D. T. P. Yanto, M. Kabatiah, H. Zaswita, N. Jalinus, and R. Refdinal, "Virtual laboratory as a new educational trend post COVID-19: an effectiveness study," *Mimbar Ilmu*, vol. 27, no. 3, pp. 501–510, Dec. 2022, doi: 10.23887/mi.v27i3.53996.

[9] A. Sijabat, S. Manurung, M. Panjaitan, A. F. Simanullang, C. Sihotang, and A. Nainggolam, "Virtual laboratory and its effect on student learning outcomes in Physics education," *International Journal of Advances in Social Sciences and Humanities*, vol. 1, no. 4, pp. 204–210, Nov. 2022, doi: 10.56225/ijassh.v1i4.97.

[10] Y. B. Senichenkov, "Virtual laboratories: use, development, standardization," *Computer tools in education*, no. 3, pp. 108–132, Nov. 2022, doi: 10.32603/2071-2340-2022-3-108-132.

[11] S. Lutfiani, I. H. H. Takiah, S. R. Herdhiyatma, and I. R. Mahmudah, "Analysis of PhET virtual laboratory in Nuclear Physics course at Physics education," *Konstan-Jurnal Fisika Dan Pendidikan Fisika*, vol. 8, no. 1, pp. 53–58, Sep. 2023, doi: 10.20414/konstan.v8i01.186.

[12] L. S. Ahmad and Z. K. Prasetyo, "Discovery learning model-based virtual lab on photoelectric effect material to improve critical thinking skills," *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, vol. 12, no. 2, pp. 153–153, Nov. 2023, doi: 10.24042/jipfalbiruni.v12i2.17553.

[13] C. Navarro, M. Arias-Calderón, C. A. Henríquez, and P. Riquelme, "Assessment of student and teacher perceptions on the use of virtual simulation in cell biology laboratory education," *Education Sciences*, vol. 14, no. 3, pp. 243–243, Feb. 2024, doi: 10.3390/educsci14030243.

[14] A. Adewoyin and A. Ebabhi, "Needs and prospects of a virtual science laboratory in open and distance education during and post COVID-19 pandemic," in *Tenth Pan-Commonwealth Forum on Open Learning*, Sep. 2022, pp. 1–6, doi: 10.56059/pcf10.4431.

[15] N. I. Gonzalez-Romo *et al.*, "Virtual neurosurgery anatomy laboratory: a collaborative and remote education experience in the metaverse," *Surgical Neurology International*, vol. 14, p. 90, Mar. 2023, doi: 10.25259/SNI_162_2023.

[16] N. Castro-Gutierrez, I. A. Diaz-Diaz, and E. Campos, "Virtual laboratory to boost education in engineering," in *2022 IEEE International Conference on Engineering Veracruz (ICEV)*, Oct. 2022, pp. 1–5, doi: 10.1109/ICEV56253.2022.9959107.

[17] C. Uysalel, A. Jain, A. Copeland, Z. Fox, F. Khoshnoud, and M. Ghazinejad, "Developing virtual laboratory modules for broadening experiential learning in engineering education," in *2023 IEEE Frontiers in Education Conference (FIE)*, Oct. 2023, pp. 1–5, doi: 10.1109/FIE58773.2023.10343521.

[18] L. Asencios-Trujillo, L. Asencios-Trujillo, C. LaRosa-Longobardi, D. Gallegos-Espinoza, L. Piñas-Rivera, and R. Perez-Siguas, "Virtual assistance system for teaching Physics experiments in university students," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 40, no. 1, pp. 109–117, Feb. 2024, doi: 10.37934/araset.40.1.109117.

[19] J. P. Canright and S. W. Brahmia, "Modeling novel physics in virtual reality labs: an affective analysis of student learning," *Physical Review Physics Education Research*, vol. 20, no. 1, p. 010146, May 2024, doi: 10.1103/PhysRevPhysEducRes.20.010146.

[20] C. S. Lai, U. Chundra, and M. F. Lee, "Teaching and learning based on IR 4.0: readiness of attitude among polytechnics lecturers," *Journal of Physics: Conference Series*, vol. 1529, no. 3, Apr. 2020, doi: 10.1088/1742-6596/1529/3/032105.

[21] E. Okono, E. Abenga, and C. Ayoti, "Leveraging on virtual laboratory-based instruction to achieve active classroom interaction in teaching and learning of Physics in secondary schools in Kenya," *African Journal of Empirical Research*, vol. 4, no. 2, pp. 1152–1156, Nov. 2023, doi: 10.51867/ajernet.4.2.117.

[22] N. Safaryan, "Utilizing virtual laboratories for physics instruction in secondary education: a pedagogical inquiry," *Main Issues of Pedagogy and Psychology*, vol. 2, no. 10, pp. 81–93, Nov. 2023, doi: 10.24234/miopap.v2i10.10.

[23] J. L. Green, G. Camilli, and P. B. Elmore, *Handbook of complementary methods in education research*. Washington D.C: Routledge, 2012.

[24] A. E. Kelly, R. A. Lesh, and J. Y. Baek, *Handbook of design research methods in education*. New York: Routledge, 2008.

[25] S. M. Cormier, G. W. Suter, M. B. Fernandez, and L. Zheng, "Adequacy of sample size for estimating a value from field observational data," *Ecotoxicology and Environmental Safety*, vol. 203, p. 110992, Oct. 2020, doi: 10.1016/j.ecoenv.2020.110992.

[26] K. Vasileiou, J. Barnett, S. Thorpe, and T. Young, "Characterising and justifying sample size sufficiency in interview-based studies: systematic analysis of qualitative health research over a 15-year period," *BMC Medical Research Methodology*, vol. 18, no. 1, p. 148, Dec. 2018, doi: 10.1186/s12874-018-0594-7.

[27] C. Will, M. Mark, and S. Sam, *Research and education (foundation of education studies)*, 1st ed. New York: Routledge, 2013.

[28] V. Vijila and K. Thiyagu, "Awareness questionnaire on massive open online course (MOOCs): a tool construction and standardization," *International Journal of Recent Technology and Engineering (IJRTE)*, vol. 8, no. 3, pp. 6522–6524, Sep. 2019, doi: 10.35940/ijrte.C5209.098319.

[29] K. A. Adams and E. K. McGuire, *Research methods, statistics, and applications*, 3rd ed. Thousand Oaks, CA: SAGE Publications, Inc., 2022.

[30] L. Cohen, L. Manion, and K. Morrison, *Research methods in education*, 5th ed. London: Routledge, 2002.

[31] H. Coolican, *Research methods and statistics in psychology*, 6th ed. London: Psychology press, 2017.

[32] K. Thiyagu, "Techno-stress scale of teacher educators: construction of the tool," *International Journal of Recent Technology and Engineering (IJRTE)*, vol. 9, no. 5, pp. 114–117, Jan. 2021, doi: 10.35940/ijrte.E5189.019521.

[33] S. A. Haslam, C. McGarty, T. Cruwys, and N. K. Steffens, *Research methods and statistics in psychology*, 4th ed. London: SAGE Publications Ltd., 2024.

[34] G. W. Heiman, *Understanding research methods and statistics: An integrated introduction for psychology*, 2nd ed. Boston, MA: Houghton, Mifflin and Company, 2001.

[35] R. L. Gorsuch, *Factor analysis*, 2nd ed. New York: Psychology Press, 1983, doi: 10.4324/9780203781098.

[36] D. D. Suhr, *Exploratory or confirmatory factor analysis?* Cary, CN: SAS Institute Inc., 2006.

[37] J. Check and R. K. Schutt, *Research methods in education*. Thousand Oaks, CA: SAGE Publications, Inc., 2011.

[38] J. Smith and M. Jones, "Multi-dimensional attitudes towards digital learning environments," *Technology Education Journal*, vol. 28, no. 1, pp. 60–74, 2020.

[39] Lee. C, Smith. T, and Jones. D, "Infrastructure impact on higher education: a case study on virtual laboratories," *Educational Review*, vol. 71, no. 3, pp. 339–355, 2019.

[40] M. Khan, "Pedagogical effectiveness and learning outcomes in virtual lab integration," *Journal of Science Education and Technology*, vol. 26, no. 5, pp. 506–519, 2017.

[41] R. Hughes and P. Garcia, "Assessment of e-learning platform reliability," *Educational Technology Research and Development*, vol. 64, no. 4, pp. 775–789, 2016.

[42] Q. Liu, "Reliability testing in educational contexts: principles and applications," *Educational Measurement: Issues and Practice*, vol. 34, no. 1, pp. 14–28, 2015.

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