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PAPER

# Effectiveness of Virtual Laboratory Teacher Training Workshops: A Kirkpatrick Model Analysis

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**ABSTRACT**

Performing laboratory experiments is an integral and unavoidable part of STEM education. The teaching efficacy of laboratory experiments can be optimized by integrating ICT-based tools into the curriculum. As teachers are the key facilitators in practical lessons, it is imperative that they adopt the latest teaching technologies, such as virtual laboratories (VLs). To achieve optimal student learning outcomes, teachers ideally undergo adequate training programs that equip them with relevant knowledge and skills to utilize VLs. As myriad training workshops and self-learning tools are available to teachers, the efficacy of training programs needs to be precisely evaluated to determine their quality and design better programs for posterity. Kirkpatrick's four-level model is suited to evaluate teaching training, as it takes into consideration holistic aspects of learning: learners' reactions, learning outcomes, behavior, and results. In this study, we conducted and evaluated a VL teacher training program in Africa, applying Kirkpatrick's model analysis. Our results indicate a significant improvement in participants' perception and attitude toward VL after attending the training. Also, the training proved to be effective in improving the learning outcomes of the participants. We found a huge hike in the number of VL users in Africa after conducting the training program, indicating the overall success of the program. It met the needs of the teachers and equipped them with the necessary skills and knowledge to utilize VLs in their teaching practices. This study may assist future trainers to design successful teacher training programs in laboratory education.

**KEYWORDS**

Kirkpatrick's model, experiments, virtual laboratory teacher training

## 1 INTRODUCTION

Globally, undergraduate, and postgraduate science education have undergone many changes in recent times, particularly in STEM (Science, Technology, Engineering, and Mathematics) education, but the requirement for performing inquiry-based experiments has remained constant [1]. Laboratory experiments are indispensable

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to students' acquisition of analytical and instrumental skills during their undergraduate studies [2], [3]. In higher education science courses, performing experiments includes collecting and analyzing data, and drawing conclusions based on findings, with or without the guidance, support, and feedback of teachers. While classroom learning remains an integral part of the educational experience, laboratory experiments are key to achieving learning outcomes [66] and improving students' cognitive abilities. Conducting experiments reinforces theoretical knowledge and improves the quality of learning [4]–[15].

Teachers play a crucial supporting role in improving students' learning curves in different fields. Past research demonstrates that the laboratory experience and close connection to teachers in the laboratory setting play an important dual role in the scaffolding of students' learning through dialogue and feedback. Recent studies posit that student progress in the laboratory may be attributed to or impeded by teaching methodologies [16]–[19]. However, teaching laboratory courses can be challenging due to large student numbers, the high maintenance costs of laboratories and equipment, and inaccessibility to or a lack of resources [20]–[23], especially in developing countries. Fortunately, Information and Communication Technology (ICT)-based tools such as virtual laboratories (VLs) can mitigate these challenges and have become a widely accepted teaching and learning technique [4], [24]–[27], [67], [68], especially during the COVID-19 pandemic. VLs are cost effective and easily accessible from anywhere, anytime, making them a valuable resource for students and teachers alike [69].

VLs have been proven to be effective in improving teaching effectiveness [28]–[30]. While not a substitute for traditional learning, VLs supplement learning activities and help improve teachers' confidence in teaching science subjects [9], [31], [32], which in turn increases the quality of teaching. Although teaching infrastructure may have largely mitigated the crisis in developing countries, effective teaching using VLs is key to harnessing technology to achieve optimal learning outcomes. Teaching effectiveness has implications for learners' academic achievements, critical thinking capacity, perseverance to excel, and overall confidence [23], [30], [33]–[36]. As such, it is essential for teachers to continuously improve their teaching skills and stay up –to date with the latest educational technologies. Teachers are encouraged to undergo training courses, such as workshops, online courses, or mentorship programs, to enhance their teaching effectiveness [37]. Training is a systematic learning process that helps employees acquire skills, attitudes, or concepts that improve their job performance [38]. It is essential to view training as a human capital investment that yields long-term benefits for the institution and its employees [37]. By investing in the training of teaching personnel, institutions can ensure that faculty is proficient in teaching skills and can deliver quality education to their students [39]–[43]. The assessment of teacher training programs is thus critical [44] in understanding the impact on students' learning outcomes, gaining valuable insights into the program's strengths and weaknesses, and helping identify areas that require improvement [45], [46]. Simply measuring learners' satisfaction through self-assessment is not enough; a comprehensive approach that measures input, training process, and output is essential [47].

We investigate the possibilities of using VL as a teaching and learning tool to improve the quality of education in Africa. VL teacher training was conducted for a group of science teachers. This study uses the Kirkpatrick model [48] to analyze the efficacy of the training given to teachers by examining teacher adoption of VL before and after training. By analyzing the attitude and acceptance of VLs by teachers from different institutions, we attempt to assess the impact of VL technology on the teaching and learning processes in Africa. This study was conducted by Amrita Vishwa Vidyapeetham in Africa in July 2022. Our analysis utilized VL experiments developed by Amrita Vishwa Vidyapeetham (accessible at https://vlab.amrita.edu/). In India, the VL project is a National Mission on Education initiative by the Ministry of Education, Government of India, through ICT, aimed at providing remote access to laboratories for undergraduate and research students in various disciplines of Science and Engineering.

## 2 THEORETICAL FRAMEWORK

Among the various models used for program assessment, Kirkpatrick's model is a highly effective and widely used approach. This model allows for the measurement of a program's impact on the learners, which is a crucial factor in determining the effectiveness of any educational program. Kirkpatrick's model is characterized by its simplicity, the measurement of a limited number of variables, ease of measuring, and independence from individual and environmental variables. While it is true that all assessment models have some deficiencies, Kirkpatrick's model has a suitable performance for assessing educational programs [49], [50].

Kirkpatrick's model comprises four distinct levels that provide a comprehensive analysis of the impact of training programs on learners: Reaction, Learning, Behavior, and Result. At the first level, Kirkpatrick's model focuses on the trainees' response to the training experience. This level assesses their level of engagement and satisfaction too. The second level evaluates trainees' learning outcomes, which include increases in knowledge, skills, and attitudes toward the training experience. This level typically involves pre and post-training assessments to measure the extent to which attendees have learned the content. The third level of Kirkpatrick's model measures the transfer of learning from the training program to the workplace. It assesses whether the learners' behavior and performance have improved after attending the training program. Finally, the fourth level measures the overall outcomes of the trainee after attending the training program.

The present study uses Kirkpatrick's model to analyze each phase of our African teacher training program. Input includes teachers, as their characteristics and abilities can significantly affect program success. The training process involves educational programs, assessment methods, and facilities provided to the trainees. The quality of the instructional materials, training delivery, and availability of facilities can significantly influence program outcomes. Output refers to participants' behavior after completing the training, such as knowledge retention, ability to apply what they have learned, and changes in behavior resulting from the training. We also investigate: (1) the overall behavior of African teachers towards ICT-based tools before the VL intervention, (2) the changes in their behavior towards ICT-based tools after the VL intervention, and (3) the effectiveness of the VL training program based on Kirkpatrick's model.

## 3 METHODS

### 3.1 Participants

In the study, the participants included 29 teachers (Table 1) from different parts of the continent (Kenya, Tanzania, Malavi, Zambia, and Uganda) from various disciplines (Figure 1). Among them, 65.51% were male, and 34.48% were female. About 19%, 30%, and 36% of the participants had over 15, 10, and 5 years of teaching experience, respectively.

**Table 1.** Demography of the participants

| | Category | N | (%) |
|---|---|---|---|
| Gender | Male | 19 | 65.51 |
| | Female | 10 | 34.48 |
| Years of experience | 1–5 years | 4 | 14.66 |
| | 6–10 years | 11 | 36.21 |
| | 11–15 years | 9 | 30.17 |
| | Above 15 years | 6 | 18.97 |

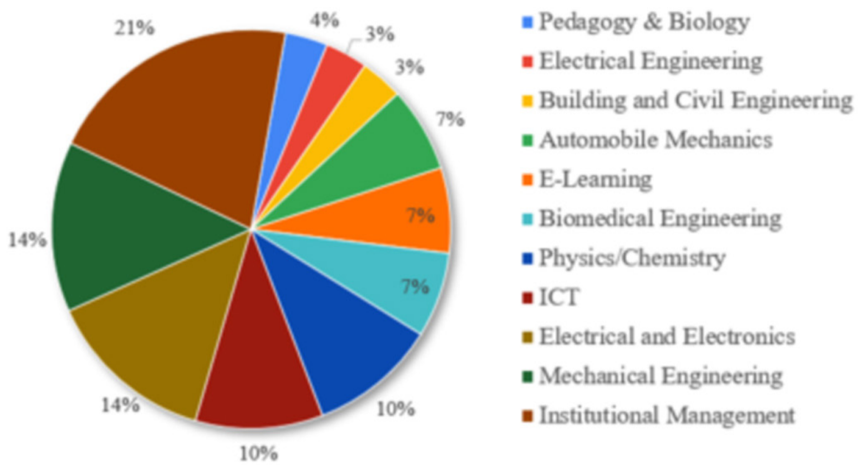


**Fig. 1.** Distribution of the participants by discipline

## 3.2 Study design

The study's adherence to Kirkpatrick's model demonstrates its rigorous and comprehensive approach to evaluating the effectiveness of VL training. The four distinct phases of the study were carefully designed to ensure that all aspects of VL experimentation were thoroughly assessed. A schematic of our study design is shown in Figure 2.

During the first phase, VL experiment developers introduced the experiments to study participants, while also gathering data on their attitudes, perceptions, and confidence about VL experimentation. This phase established a baseline understanding of participants' pre-existing knowledge and attitudes toward VL experiments. The study's second phase involved VL demonstration and training participants on conducting VL experiments and utilizing the VL Learning Management System (VL-LMS) module [51]. During this phase, the study evaluated the participants' knowledge and skills in conducting experiments. The third phase of the study focused on the effective implementation of VL experiments in the participants' respective institutions. Observing and analyzing the participants' adoption behavior was critical in determining how effectively the training translated into practice [52]. Finally, in the fourth phase, the study assessed training outcomes using usage data of participants and institutions collected through Google Analytics. This phase provided valuable insight into the long-term effectiveness of the VL training and whether it resulted in a sustainable change in behavior.

It is undeniable that gathering feedback from participants is an essential component of evaluating the effectiveness of any training program. In this regard, the use of general feedback surveys and interviews with participants was considered an effective way of obtaining their opinion on the content of the VL platform and the training provided. Hence, we collected feedback surveys regarding the content of the VL platform and general training of the VL. Interviews with the participants were also conducted to support the feedback. We also collected immediate responses from participants on program design, program content, and program outcome to make necessary adjustments to enhance future workshops. A schematic illustrating different levels of our program execution is shown in Figure 3.

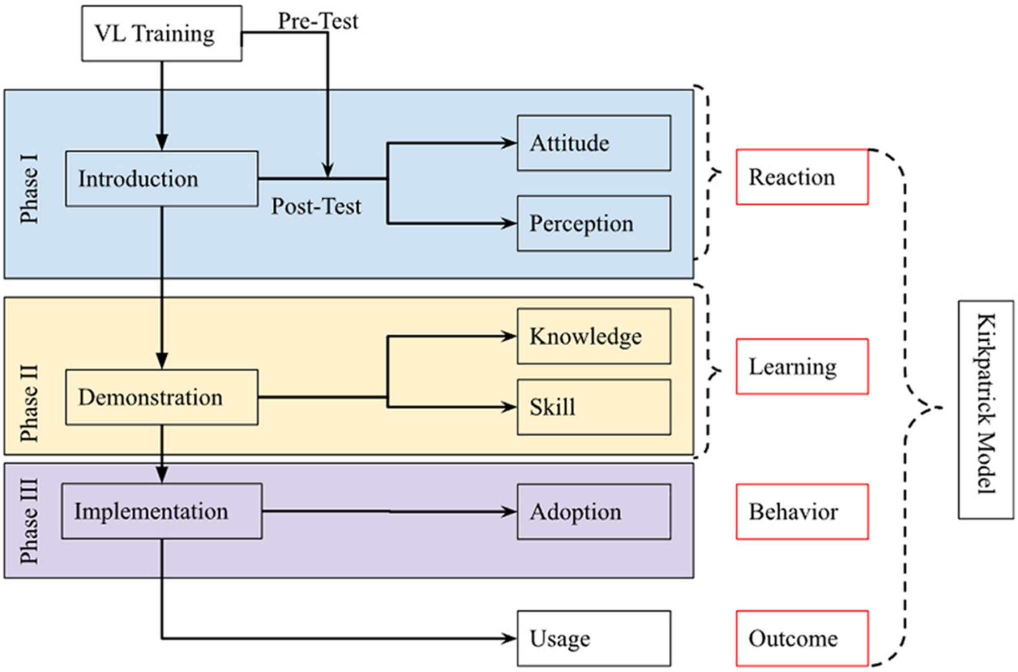


**Fig. 2.** Study design

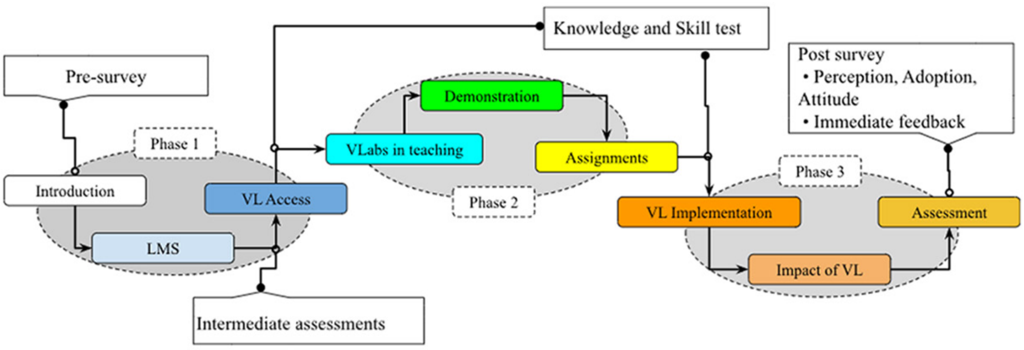


**Fig. 3.** Program design

### 3.3 Data collection and analysis

We evaluated attitudes towards and perceptions of VL—i.e., reaction level of the Kirkpatrick evaluation model—using a 5-point Likert scale questionnaire adapted from [53] and [54], given to the participants (Section B of the supporting document). The questionnaire included 13 questions and the scale ranged from Strongly agree (5 points) to Strongly disagree (1 point). Internal consistency was measured using the

Cronbach alpha (α) [55]. Out of the 13 questions, 8 (α=0.78) were designed to measure teachers' attitudes toward VL use, and the remaining 5 (α=0.82) measured teachers' perception towards VLs. VL knowledge and skill of the participants were assessed in the second phase (i.e., learning) of the Kirkpatrick evaluation model. Knowledge was assessed using pre-test and post-test [56] questionnaires comprising ten multiple-choice questions (MCQs) each (Section C of the supporting document). Skill was measured based on the time taken by each participant to complete three assignments (Section C of the supporting document) during the demonstration. It is noted that repeating an assignment multiple times leads to familiarity, which may significantly impact the time taken to complete the task. Therefore, participants were allowed to do a particular assignment only once, thereby ensuring that the results accurately reflect their initial performance and avoid any potential bias. We designed the MCQs to measure participants' basic knowledge of the VL platform. The third level of the Kirkpatrick evaluation model, behavior, was assessed using another questionnaire [53], [57] of 20 questions (α=0.86), which addressed the willingness of each participant, after the implementation of VL experiments, to adopt VL as a teaching tool in their institution. To assess the fourth level of the Kirkpatrick evaluation model, result/outcome, we collected the usage statistics of VL from Google Analytics in Africa from October 2021 to February 2023. We conducted a two-sample paired t-test analysis to draw our results. The t-test, done for individual phases, is summarized in Table 2.

**Table 2.** T-test analysis

| | | N | M | SD | t | p |
|---|---|---|---|---|---|---|
| **Reaction** | | | | | | |
| Perception | Pre | 29 | 3.97 | 0.57 | –11.87 | 0.000 |
| | Post | 29 | 4.72 | 0.34 | | |
| Attitude | Pre | 29 | 3.44 | 0.86 | –9.49 | 0.000 |
| | Post | 29 | 4.45 | 0.62 | | |
| **Learning** | | | | | | |
| Knowledge | Pre | 29 | 2.76 | 1.34 | –24 | 0.000 |
| | Post | 29 | 7.74 | 1.45 | | |
| Skill (time taken to complete) | Pre | 29 | 97.65 | 14.16 | 23.52 | 0.000 |
| | Post | 29 | 52.47 | 14.62 | | |
| **Behavior** | | | | | | |
| Adoption | | 29 | 4.35 | 0.69 | | |

# 4 RESULT AND DISCUSSION

## 4.1 Reaction

The evidence in Table 2 indicates a clear and statistically significant improvement in participants' perception and attitude toward VL after attending the workshop. The mean and standard deviation of both pre- and post-workshop perception and attitude scores demonstrate a notable increase, which is supported by significant t-values of –11.87 and –9.49 for perception and attitude scores, respectively. The results indicate that participants gained a better understanding and appreciation of VL due to the effective training. Similar results in various scenarios are reported by [58]–[61].

## 4.2 Learning

Table 2 indicates an improvement in the knowledge level of the participants, with a significant t-value of –24. The results were obtained on the basis of a pre- and post-knowledge test given in the form of questionnaires, as discussed in Section 3.3. Then the participants were assigned some experiments without prior knowledge about the VL platform, and they were required to record the time they took to complete them. The same experiments were then repeated after the participants had received hands-on training. It was evident that the participants experienced a remarkable reduction in the time taken, roughly half (Figure 4), in completing the experiments after the training. This indicates the enhancement in the learning outcome of the participants, which is supported by the statistics, M=97.65, SD=14.16 (pre) and M=52.47, SD=14.62 (post), with $t(27)=23.52$, $p < 0.05$, as indicated in Table 2. The result obtained could be attributed to the success of the second phase of the training program, which could be confirmed based on the results of previous related studies [62], [63].

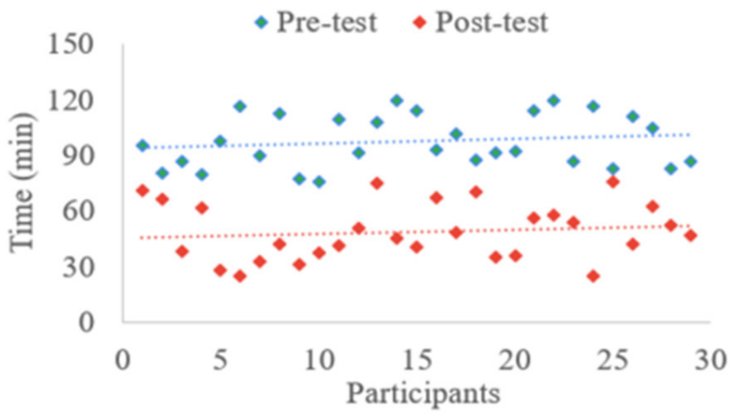


**Fig. 4.** Average time of completion of assignments using the VL platform

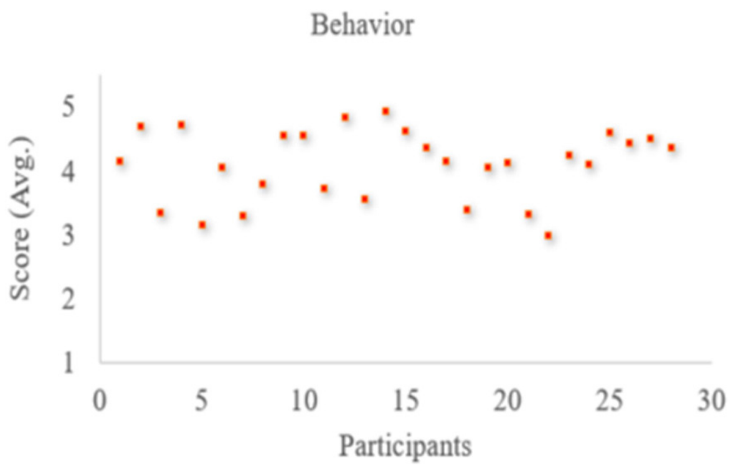


**Fig. 5.** VL adoption score of the participants

## 4.3 Behavior

Figure 5 shows the trend of VL adoption by each participant and their willingness to use the VL platform in their institution. We converted the 5-point Likert scale questionnaire responses to average scores ranging from 1 to 5. Even though the average score of each participant shows variation from individual to individual, it is noted that no responses were below the Likert score of 3, which means that nearly all the participants agree or strongly agree with VL adoption. This could be attributed to the success of the first and second phases of the training program. This is also evident from the responses of the participants given in Section A of the supporting document. We find this results in strong agreement with that reported by [64], stating that the reaction and learning levels have a strong impact on the behavior level.

### 4.4 Outcome

To measure the training outcome, the VL usage statistics from Africa from October 2021 to February 2023 were exported from the VL dashboard. The statistics reveal that daily VL users in Africa increased from 0–255 to 61–1154 after the VL intervention (20-July-2022) (Figure 6). This huge hike in the number of users could be attributed to the effectiveness of the training. Our analysis using Google Analytics indicates that the location of VL users in Africa is highly correlated with the institutions of the teachers who participated in our training program. Therefore, it is reasonable to draw a conclusion that our training program has been effective in reaching its target audience. This information not only throws light on the success of our training program but also provides valuable insights for future outreach efforts and program design in the educational sector.

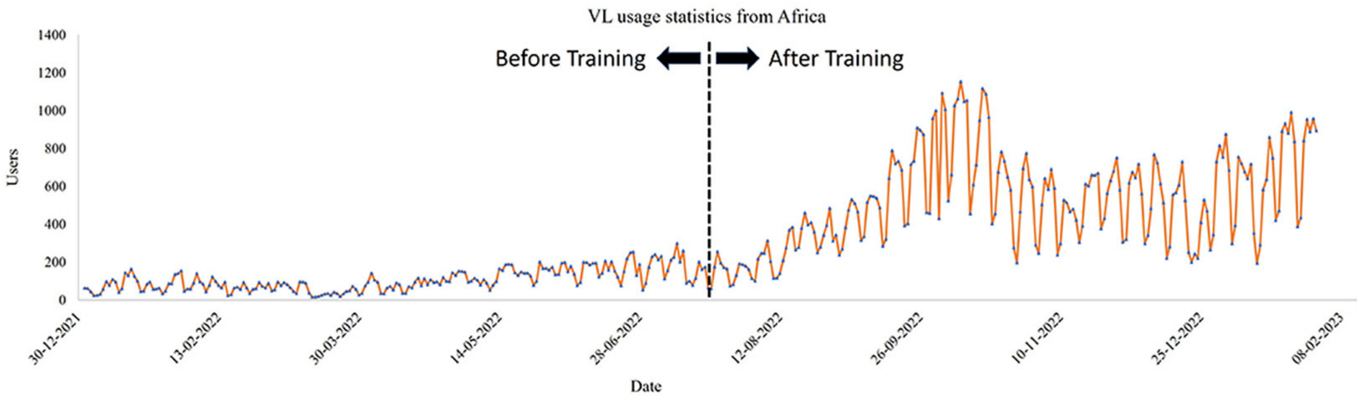


**Fig. 6.** Usage of VLs

### 4.5 Immediate feedback

From the general feedback collected from the participants (Figure 7), we found that the overall quality rating of VL leans towards "good" or "excellent." Immediate responses of the participants after the workshop on program design, program content, and program outcome are shown in Figure 8. Responses indicate that most of the participants either "strongly agreed" or "agreed" with almost all the questions (Section B of the supporting document). Some of the interview reports from participants (Section A of the supporting document) support our findings. It is evident from the responses of most of the teachers that the VL platform is not well known among them, which is interesting in post-COVID times, when VLs have gained immense popularity. However, the training program provided them with an opportunity to gain knowledge about VLs.

From the face-to-face conversations between trainers and trainees (Section A of the supporting document), the academic scenario of Africa is clear. The challenges faced by students in Africa to access education are not only limited to difficulty reaching college but also extend to inadequate equipment and chemicals, poor laboratory facilities, and unreliable internet connections. These challenges significantly impact the quality of education and limit the opportunities available for students to develop their skills and knowledge. Without a stable internet connection, students are limited in their ability to access online learning materials, and their overall learning experience is negatively impacted. In this scenario, VLs, easily accessible using a smartphone could help them to a vast extent. It is evident from the responses that VLs have proven to be an effective tool in increasing students' confidence levels and promoting self-learning. These are in accordance with [65], who found that satisfaction predicts successful achievement of learning outcomes.

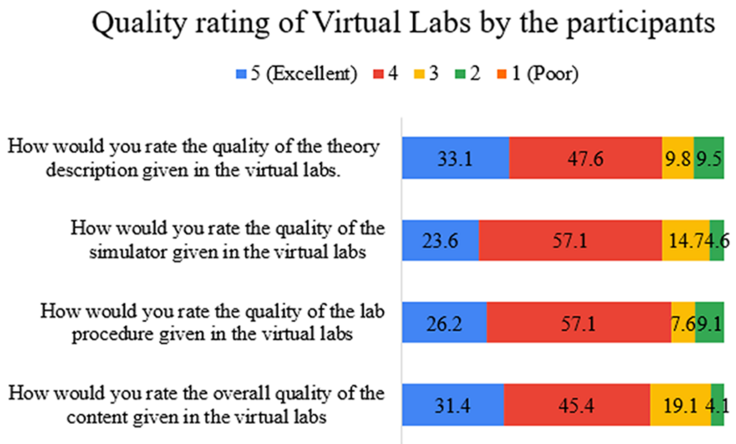


**Fig. 7.** Participants' rating of the VL platform. Numbers represent % of participants who responded

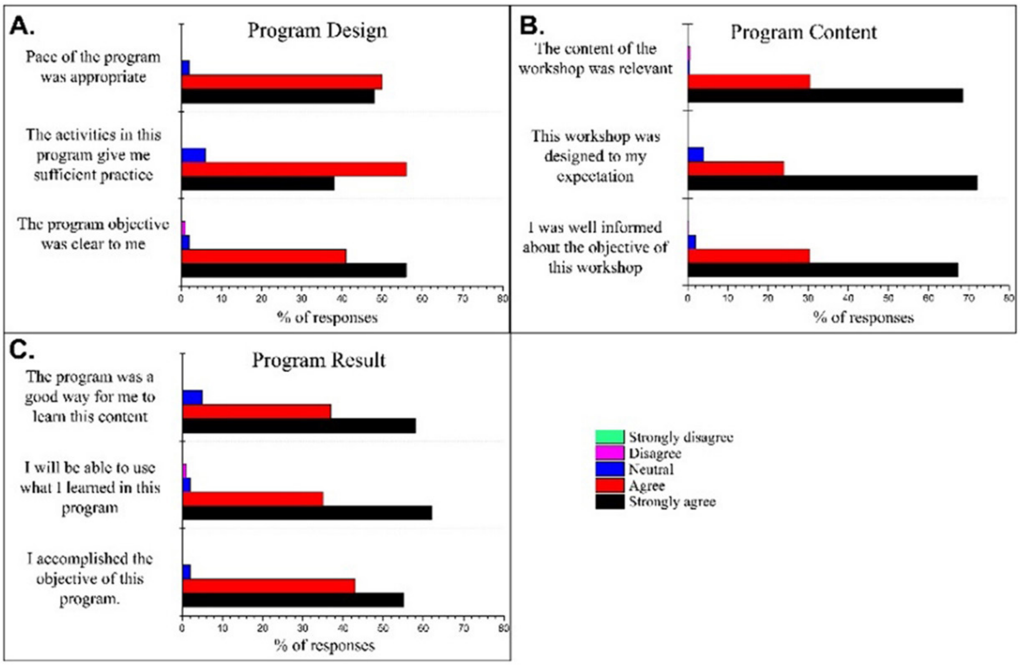


**Fig. 8.** Immediate responses from the participants after the workshop

## 5 CONCLUSION

The analysis of teachers' training programs and teachers' attitudes and acceptance towards VLs in this study is an important contribution to understanding the potential impact of VLs on education in Africa. By evaluating the effectiveness of VL training programs using Kirkpatrick's model, this study provides a comprehensive assessment of the value of VLs as a teaching tool. Through this study, we aim to demonstrate that VLs have the potential to revolutionize the way science is taught in Africa and can be an effective tool for improving student outcomes. The evaluation of VL training programs using Kirkpatrick's model provides a rigorous framework for assessing the impact of VLs on teachers' knowledge and skills and on the quality of education, they can deliver. The findings of this study will be important for educators, policymakers, and researchers interested in improving science education. By demonstrating the effectiveness of VLs and the value of comprehensive training programs, this study will help to make the case for greater investment in technology-enabled education.

## 6 LIMITATIONS AND FUTURE ASPECTS

Although this study focuses on the effect of technology training on teachers' acceptance of technology such as virtual laboratories, it has some limitations that should be noted. Firstly, key moderators, such as gender, experience, and age, were only superficially assessed in this study; further research is needed to investigate these factors more deeply. Secondly, the small sample size may limit the generalizability of the findings to other contexts and populations, particularly in regions where access to ICT-based tools is limited or unaffordable. Furthermore, investigating contextual and cultural determinants across teachers from various disciplines would provide a more comprehensive understanding of the barriers to adopting various types of virtual laboratories. Future research should aim to address these limitations to gain a more thorough understanding of the relationship between technology training and teacher acceptance of technology. However, seeing the encouraging responses, addressing these limitations, and conducting more extensive studies could expand this study to represent diverse samples.

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**Availability of data and materials**: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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