Effectiveness of Virtual Labs on Advanced Level Physics Students' Performance in Simple Harmonic Motion in Kayonza District, Rwanda

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Abstract

This research study investigates the effectiveness of virtual labs on Advanced level physics students' performance in simple harmonic motion. A quasi-experimental pre-test-post-test design was adopted. Participants that comprised the sample were 130 senior five secondary school students from four Rwandan schools. This sample was stratified into two groups: comprising 66 in the control group and 64 in the experimental group. Conventional teaching methods were used to teach simple harmonic motion to the control group, whereas an extensive virtual lab was used to teach the same topic to the experimental group. Pre- and post- tests were given to both groups. The difference in mean of pretest outcomes between control and experimental groups is not significant. While the comparison of mean showed a significant difference between experimental and control groups considering post-test outcomes. The study's questions were answered using the mean and standard deviation, and the independent sample t-test was utilized to evaluate the hypothesis at ($p = 0.05$). This suggests that students' access to virtual labs improves their academic performance in simple harmonic motion in contrast to the group that wasn't exposed to it. The findings indicate that the number of students who scored very well was raised up from 3 (2.3%) students with an overall mean score of 7.38 before treatment to 50 (39%) students with an overall mean score of 27.73 after the intervention. Based on the results of this study, Rwandan secondary schools that teach physics are recommended to use virtual laboratory for teaching the subject.

Keywords: virtual lab; academic performance; simple harmonic motion; conventional teaching approach

Introduction

Physics is considered as a difficult subject (Tuyizere & Yadav, 2023). However, using good teaching methods and appropriate materials, it can be made interesting to students. Laboratory is paramount important for teaching science, including physics. Students can better understand the theory's applicability with the use of a physics lab, which also helps them understand the subject's fundamental ideas (Soliman et al., 2021). As with other natural science fields, lab work is crucial to the study of physics. In addition, students' curiosity and favorable attitudes toward science are increased by the actual experiments (Ambusaidi et al., 2018). Although vitally important, laboratory work nevertheless presents a number of difficulties, including the high cost of laboratory supplies and materials, and the risks associated with

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working on equipment (Hamed and Aljanazrah, 2020).

The literature review demonstrates how a combination of information and communication technologies like simulations, animations, movies, and visualizations with actual practical labor is a promising ingredient for teaching and learning physics. Combining a virtual lab with a real lab is one way to use ICT in physics education (Mihret et al., 2022).

According to Usman et al. (2021) virtual laboratory system provides practical STEM education to students who do not have access to traditional, physical laboratories. Applying a successful virtual laboratory in learning and teaching of physics can be useful (Jain & Kaur, 2022). The effect of utilizing virtual experiments and virtual labs in improving teaching and learning physics, as well as the question of whether such experiments can replace actual lab work and/or improve students' performance, are constantly up for discussion (Yildirim, 2020).

To assist students in developing scientific curiosity and practical skills, it is also vital to design successful learning environments that are better tailored to their requirements in the digital era (Kiryakova et al., 2018). The teaching and learning are evolving globally as a result from information and communication technology. One of the most popular educational technologies used nowadays in classrooms is virtual learning environments (Cheung et al., 2021). (Hernandez-de-Menendez et al. (2020) state that teaching using virtual model, students can experience the physical sensation of being in the lab, which provides them confidence as they advance to an actual lab setting. In 2015, Rwanda moved to a competency-based curriculum, which recommends a practical and skills-based approach to learning. Moreover, it orients students toward the requirements of the workplace. The new curriculum highlights the importance of STEM education and basic scientific competencies for students to develop.

Additionally, Rwanda has been working hard to digitize teaching and learning materials. One of the most recent developments in educational software is virtual labs. The Rwandan government through the Rwanda Basic Education Board in partnership with GIZ, is considering the creation of a virtual laboratory as an alternative solution to promote scientific skills and confidence among students. The virtual lab can help to overcome many challenges in teaching STEM subjects in primary and secondary schools in Rwanda. Various Studies have shown that the use of computer simulation experiments can have positive effects on Rwandan physics students' performance (Ndihokubwayo et al., 2020). This research study examined the effectiveness of virtual labs on Advanced level physics students' performance in simple harmonic motion in Kayonza District, Rwanda

Literature review

Learning physics via virtual lab as a learning medium has enhanced students' conceptual knowledge (Putri et al., 2021). Several researchers in science education reported a considerable gain for both male and female students while teaching using virtual laboratories (Gunawan et al., 2020). Virtual laboratories draw students' attention with their visual displays and direct engagement, encouraging them to think critically and experiment with many conceptual variables in ways that are both constructive and effective for teaching (Shimba et al., 2016). Virtual labs offer a convenient and cost-effective way to support lab education. Some use virtual labs as a substitute for hands-on labs, but it has been reported that this has been unsatisfactory for students and in some cases has had negative effects (Burkett & Smith, 2016). However, virtual labs can be an important complement to hands-on labs (Shimba et al., 2016).

Virtual labs, include virtual operating systems, computer screens, and science labs (Khairudin et al., 2019). Virtual laboratories are interactive, digital simulations of tasks that are frequently carried out in actual laboratory environments, where tools, equipment, tests, and procedures used in chemistry, biochemistry, physics, biology, and other courses with a lab component in the curriculum are replicated in virtual labs (Gamage et al., 2020).

As stated by Bortnik et al. (2017) virtual lab has potential to assist and improve in-person practical learning. Computers and related technologies are now present in the majority of schools worldwide as a result of the tremendous expansion in the usage of computers in education over the past few years (Sibomana et al., 2021). Without a question, science classrooms have seen a significant increase when it comes to utilize of information and communication technologies (ICT). This is not just because technology goes over to support the individual with many life skills, but also because it offers more than one option for science teachers to overcome teaching challenges and enhance learning results (Oser & Fraser, 2015). One of the most recent developments in ICT is the virtual lab, which has replaced traditional laboratories. Interesting opportunities exist for students to access educational content through virtual labs. According to Ambusaidi et al. (2018) virtual labs have pedagogical potential because they allow for "learning by doing for everyone". According to research results from Hamed and Aljanazrah (2020) the use of virtual physics laboratories, particularly in regions with a severe lack of laboratory equipment makes physics teaching and learning more meaningful for the students.

It is impossible to overstate how crucial practical activities are to students' understanding of physics. According to Antwi et al. (2021), practical physics activities enhance students' learning, support the development of good attitude toward physics, and most importantly, encourage the retention of information. Duschl and Grandy (2008) outlined the following objectives for employing labs in scientific education: To assist students in developing their inquiry and analytical skills, as well as their practical skills, positivity toward science, and ability to understand complex and challenging scientific concepts using real-world situations.

Through laptops and cellphones, students can learn scientific topics and acquire new abilities utilizing a virtual lab at anytime and anywhere (Sung et al., 2016). In a virtual lab, students will have more chances to make many trials than they would in a real one, which will increase their confidence while doing genuine work. Students can also conduct experiments in a virtual lab that would be difficult to accomplish in a physical lab because of a lack of resources, the high cost of materials, or potentially dangerous situations (Sithole et al., 2020). Additionally, students can examine graphic presentations of natural events, gather data, make predictions, and formulate hypotheses in virtual labs, allowing them to actively participate in scientific research processes (Schnieder et al., 2022).

Virtual labs provide simulated versions of traditional laboratories where learners have access to items which are virtual presentations of the real objects used in traditional laboratories, in accordance with a student-centered approach. Through hands-on learning, fun and stimulating activities that encourage exploration, and ensuring active involvement in class discussions and debates, virtual laboratories may aid in teaching and learning processes (Christopoulos et al., 2018).

Using time in convenient manner, virtual laboratories can give students the chance to research scenarios that cannot be explored in real life (Faour & Ayoubi, 2018). Additionally, they are useful for studying complex ideas like relativity and experimentation that cannot be studied or implemented in conventional laboratory settings. According to Herga et al. (2016), virtual laboratories provide remarkable visualization and graphical analytical skills as well as a visual context for many abstract subjects.

In order to conserve time and space, virtual lab equipment is used. They save more time than traditional hands-on laboratories since they are easier to construct and use properly than actual laboratory equipment (Faour & Ayoubi, 2018). They could tackle the issue of crowded gatherings and facilitate interaction between non-visual or auditory learners and their learning environment. Because it fills in the understanding and background gaps and offers an engaging social experience for students, virtual labs may be thought of as educational opportunities (Sapriati et al., 2023).

Through the use of computer technology, virtual experiments are delivered to students, adding value to physical experiments (Xenofontos et al., 2016). Virtual lab allows students to explore phenomena that are not visible to the naked eye, make connections between visible and invisible phenomena, highlight salient information, and carry out several experiments quickly (Radu & Schneider, 2019). In addition to, offering online life and flexible guidance, virtual labs save money because modern lab materials and substances can be expensive to operate in traditional laboratories due to both their scarcity and high running costs (Chakravarti et al., 2021). Virtual laboratories also allow for the safe performance of hazardous experiments (Oladejo & Akinola, 2022). Numerous research findings demonstrate that the virtual lab is user-friendly and offers feedback at the completion of the internship simulation, making it an effective teaching tool to increase students' understanding and motivation (Chacko & Kapila, 2019). Despite all the benefits, some researchers noted a few drawbacks, such as the students' shortage of a hands-on approach and the absence of a lab partner who may foster peer learning (Oser & Fraser, 2015).

Aims and significance of the study

The aim of this research is to investigate the effect of virtual experiments on students' performance in simple harmonic motion in Kayonza District, Rwanda. The study is mainly guided by a research question: *What effect do virtual lab teaching tools have on senior five physics students' performance in simple harmonic motion in selected secondary schools in Kayonza District?* The study will be helpful to students since they will be motivated to study more diligently and increase their retention of materials as well as engaging them in the learning process. The study will also be useful for physics teachers as they can utilize it for an effective teaching method.

Research Methodology

The research design of the present study is quasi-experimental non-equivalent group. Additionally, Pre- and post- tests were used to assess the effectiveness of the virtual labs as well as the way to supporting the authors in comparing students' performance from both control and experimental groups after treatment.

Sample and Sampling method

The sample size of this study is made of 130 students of senior five from four public secondary schools in Kayonza district who participate in the academic year 2022–2023. Stratified sampling was used to divide the population into two groups or strata. In this study, each stratum is made up of two schools found in the district cities and rural area of Kayonza district. Male participants made up 48.5 percent of the sample in this study, which included 63 students, 32 of whom were in the control group and 31 were in the experimental group. There were 67 students in total who were female participants (51.5% of the sample), and that 33 were from the experimental group, 34 were from the control group as shown in Table 1.

Table 1 Distribution of sample size

	Male *f* (%)	Female *f* (%)	Total *f* (%)
Experimental group (N = 64)	31 (48.4)	33 (51.6)	64 (49.2)
Control group (N = 66)	32 (48.5)	34 (51.5)	66 (50.8)
Total	63 (48.5)	67 (51.5)	130 (100)

Two student groups from four selected schools, will be compared in this regard: an experimental group 64 participants in which the traditional method was replaced by a virtual session using appropriate Virtual lab simulations for simple harmonic motion followed by practical work; and a control group of 66 students who studied the topic utilizing the conventional method (face-to-face lecture followed by practical work). Two teachers received training on how to utilize virtual labs in the teaching and learning process and were recommended using them in this study. While in the control group, two teachers from two different schools were teaching simple harmonic motion without the use of a virtual lab.

Data collection

Quantitative data were collected by the use of test about oscillations and waves in which students 'scores from both control and experimental group were assessed before (pre-test) and after (post-test) teaching using conventional methods or virtual labs respectively. In both post-test and pre-test, the learning objectives regarding SHM through the current national curriculum in Rwanda were emphasized. Simple harmonic oscillators, equations of simple harmonic oscillation, the kinematics of simple harmonic oscillation, energy changes and its conservation in oscillating systems, and the superposition of same-frequency harmonic motion were some of these topics. For the purpose of validity, the length of these tests was taken into account. This means that these assessments shouldn't be too short or too long to avoid losing their relevance to the subject matter for the students. Before collecting the data using this questionnaire, a piloting study was conducted to check whether this instrument is reliable. Internal consistency was assessed by computing Cronbach's Alpha and it was found to be reliable as well as the reliability index is 0.830.

Students from the control group were exposed to virtual laboratory teaching tools after all the necessary data had been gathered, and their teachers assisted them in reviewing simple harmonic motion concepts by working with one of the researchers in a manner that was very similar to how the intervention on the experimental group had been conducted. This was done to ensure that all students from both groups received an equal opportunity and that none fell prey to the present research.

Data analysis

The gathered data have been analyzed and interpreted in this section. To determine all potential correlations and existing patterns between the variables, several outcomes from both descriptive and inferential statistics have been applied with SPSS. The analysis of data was mainly focused on the mean, standard deviation, mode, maximum and minimum marks using descriptive statistics. While utilizing independent samples t-test and Cohen's d-value, respectively, to examine the significance of the mean difference and magnitude of the mean difference. More deeply Hake's normalized learning gain factor was used to investigate deeper and comprehend more about the efficacy of an intervention used in this research.

Results and Discussions

Pre-test results reveal that, when comparing the learning outcomes of students from the control group with that from experimental group on the pre-test, the average marks were not apart from one another. As described in Table 2, the mean score of 7.47 out of 50 for the control group and 7.30 out of 50 for the experimental group was noted.

Table 2 **Outcomes from pre-test for the experimental and control group**

Group	N	Mean	Std. dev.	Mean difference	Sg.	T	df.	p-value
Control	66	7.47	5.01	0.17	0.728	0.193	126	0.85
Experimental	64	7.30	5.09					

An independent sample t-test, as shown in Table 2 above, demonstrates that there was no statistically significant difference between the pre-test mean scores of students in the control (M = 7.47) and experimental groups [M = 7.30, t (126) =0.193; p=0.85]. We draw the conclusion that students in the control and experimental groups were academically at the same level before the intervention since there was no statistically significant difference between their pre-test mean scores.

Impact of the Virtual lab on students' post-test scores for the experimental and control groups

Even though it is obvious that both teaching methods have benefited the students, we want to know which one has performed better statistically.

The average post-test score for students in the control group was 24.19 out of 50, whereas that for students in the experimental group was 30.10 out of 50, as shown by Table 3 which indicates the comparison of the two groups' mean scores.

From Table 3 above, the variation in post-test mean scores between the experimental and control groups of students was found to be statistically significant between control group (M = 24.19, and experimental group [M = 31.10, t (125) = 4.788; p = 0.001]. The findings reveal that there is a significant difference on students' test results while

Table 3 **Outcomes of the post-test for the experimental and control groups**

Group	N	Mean	Std. dev.	Mean difference	t	df.	p-value	Cohen's d	Sig
Control	66	24.19	8.283	6.908	0.193	126	0.001	0.85	0.306
Experimental	64	31.10	7.974						

teaching simple harmonic motion using the virtual lab resources.

To gauge the effect size of the virtual lab teaching tools, the Cohen's d value was calculated.

A significant effect size of 0.85 was found, indicating that students within experimental group outperformed the control group in relation of test results by 0.85 standard deviations. It was found that following the intervention, there was a 72.6% chance of learners in the treatment group that would have higher test scores than the control group in simple harmonic motion unit, and that 80.2% of students in the trial group had scores that were higher than the mean of the control group.

A normalized gain was also utilized for deeper understanding and comprehend more about the efficacy of an intervention used in this research.-Hake's learning gain factor <g> was used to compute a normalized gain of the effect of the intervention (Hake, 1988). It has been computed mathematically as:

$$average\ \ g = \frac{average\ marks\ in\ post\ test - average\ marks\ in\ pretest}{maximum\ marks - average\ marks\ in\ pretest}$$

$\langle g \rangle = \frac{31.10-7.3}{50-7.3} = 0.56$ for experimental group.

$\langle g \rangle = \frac{24.19-7.47}{50-7.47} = 0.4$ for control group.

The normalized learning gain factor <g> was found to be 0.4 and 0.56 for the experimental group and the control group, respectively. The experimental group's learning gain factor is 1.4 times more than control group. This shows that, following the intervention, there was an improvement in conceptual understanding in simple harmonic motion topic. The conceptual knowledge level of Rwandan students in the experimental group was about 1.4 times greater than the conceptual knowledge level attained by students in the control group.

These findings are in line with a number of previous studies that found using virtual labs improved students' conceptual knowledge. According to Hamed & Aljanazrah (2020), students who received instruction using a virtual lab fared better on assessments of conceptual knowledge and more quickly advanced their ability to operate genuine equipment. Using time in a convenient manner, virtual laboratories can give students the chance to research scenarios that cannot be explored in real life (Faour & Ayoubi, 2018).

Additionally, they are useful for studying complex ideas like relativity and experimentation that cannot be studied or implemented in conventional laboratory settings. Virtual laboratories provide remarkable visualization and graphical analytical skills as well as a visual context for many abstract subjects. The outcomes of this study are consistent with those of Santos and Prudente (2022) who looked at the effects of virtual labs on performance of students in physics found that their use improves students' performance.

Conclusion

The national vision of Rwanda states that the economy of the nation must be knowledge- and technology-based (Abdulwahed, 2017). To achieve this objective, Rwanda undertook a series of changes to its educational system, which culminated in the implementation of a competency-based curriculum (Ndihokubwayo & Habiyaremye, 2018). To be effective, a competency-based curriculum must be presented utilizing learner-centered teaching techniques.

The findings of this study have furthered the argument made in earlier investigations. Through this study, it has been proven that teaching simple harmonic motion using a virtual lab has potential to enhance academic performance of students. In this investigation, it was shown that the post-test mean score of students in both experimental and control groups differed statistically significant [t (125) =4.788; p=0.001]. These findings show that teaching simple harmonic motion via virtual lab has beneficial effect on both academic performance of students as well as their theoretical comprehension and therefore be implemented in Rwandan physics schools.

Furthermore, they provide students with access to a real-world lab setting where they may do experiments and refine their skills in a secure and interesting learning environment. The following are the two primary conclusions, which can be summed up based on the various parameters used to analyze the results of this study:

1. The academic achievement of students in Rwanda's senior secondary schools is improved by the aid of virtual labs in the teaching and learning of physics.
2. In Rwandan secondary schools, the role of interactive virtual labs in physics instruction enables the students to carry out various experiments without being restricted by location or time.

Based on these important conclusions, it is advised to all parties concerned that virtual lab be incorporated and put into use during teaching and learning of the physics subject in Rwandan secondary schools that provide physics classes.

Recommendations

Based on the information acquired throughout the study process and the research findings, we suggest the following recommendations and areas for further investigation:

1. Physics teachers should attend seminars or training on the use of the virtual lab tool in order to thoroughly understand its operation and apply this technique in teaching and learning physics.
2. School officials should provide funding for the purchase of sufficient computers and internet access so that computer-aided instruction—like virtual labs -- can be used in physics classes.
3. When developing physics curricula and authoring physics textbooks, REB should use sources of ICT tools (virtual lab) and their user manuals.

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