Journal of Mathematics and Science Teacher
2023, 3(2), em043
e-ISSN: 2752-6054
https://www.mathsciteacher.com/

MODESTUM

Research Article

OPEN ACCESS

Effect of computer-simulated teaching tools on Rwandan senior four students' understanding of graphs of projectile motion

Jean Claude Uwayezu [1*], Lakhan Lal Yadav [1]

[1] African Center of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), University of Rwanda-College of Education, Rukara Campus, Kayonza, RWANDA

***Corresponding Author:** basanande2014@gmail.com

Citation: Uwayezu, J. C., & Yadav, L. L. (2023). Effect of computer-simulated teaching tools on Rwandan senior four students' understanding of graphs of projectile motion. *Journal of Mathematics and Science Teacher, 3*(2), em043. https://doi.org/10.29333/mathsciteacher/13593

ARTICLE INFO

Received: 28 Aug. 2022

Accepted: 09 Aug. 2023

ABSTRACT

This study intended to assess the extent to which computer-simulated teaching tools influence Rwandan senior four students' understanding of graphs of projectile motion. Two schools were purposively selected, and 54 students were grouped in the control and experimental groups. Students' scores on a multiple-choice test were collected and analyzed using frequencies and inferential statistics. Results showed that students in the experimental group got the average normalized gain in the medium range, $t(36)=3.944$, $p<0.01$ whereas in the control group it was in the low range, $t(16)=1.788$, $p>0.05$. It was found that students in the experimental group improved their understanding of graphs of projectile motion better than students who were taught using traditional methods, $t(52)=-2.194$, $p=0.033$. The study shows that using computer-simulated teaching tools influences positively students' understanding of graphs of projectile motion. The use computer-simulated teaching tools in teaching projectile motion is recommended for physics teachers and further studies.

Keywords: computer-simulated teaching tools, GeoGebra, PhET, projectile motion, understanding graphs

INTRODUCTION

Graphical representation of motion is an essential competency that needs to be taught to physics students to help them improve their performance in science. Graphs help to link actual motion and physics concepts (Volkwyn et al., 2020). Despite being valued in science education, the literature demonstrates that graphs of motion are challenging to students in conventional educational settings (Antwi et al., 2018; Hill & Sharma, 2015; Mešić et al., 2015; Piten et al., 2017; Shodiqin & Taqwa, 2021). According to numerous earlier research, this issue is connected to the general learning challenges that students encounter when studying mechanics topics. Some of them highlighted the inability of traditional instruction to remove students' misconceptions related to kinematics (Kibirige & Lehong, 2016; Kirya et al., 2021; Ndihokubwayo et al., 2021; Pineda, 2020) and others on conceptual learning in motion-related topics in general (Buber & Unal, 2017; Docktor et al., 2015; Kirya et al., 2022; Lestari & Mansyur, 2021). However, in many studies, little focus is put on the connection between conceptual learning and graph skills in the topic of kinematics including projectile motion.

Many studies in the literature show that teaching graphical representation of projectile motion in classroom needs efficient and effective teaching methods. First, it is agreed in many studies that students build misconceptions on projectile motion either before or during learning projectile motion (Aslan & Buyuk, 2021; Hidayatulloh et al., 2021; Mudau, 2014). Secondly, different gaps in students' graph skills are associated with the teaching and learning strategies in practice. These strategies are weak to handle the vector nature of kinematics quantities in projectile motion.

In the competence-based curriculum (CBC) adopted in Rwandan secondary schools, the topic of projectile motion is taught in senior four and it considers both the conceptual understanding and graph skills. Specifically, graph skills are among the competencies assessed in the national examination of physics for the advanced level (REB, 2015). Although Rwandan senior six students' difficulties in graphical representation of linear motion were linked to traditional teaching methods mostly used by physics teachers (Uwizeyimana et al., 2018), research on graph abilities for projectile motion in the Rwandan setting has not been made in any way. The current study intended to answer the research question: To what extent do computer-simulated teaching tools influence senior four students' understanding of graphs of projectile motion in comparison with the traditional methods? The study has also employed the following null hypothesis:

H0. There is no significant difference between students' understanding of graphs of projectile motion when taught with CBC methods assisted by computer-simulated teaching tools and when taught with the traditional methods only.

LITERATURE REVIEW

Graphical literacy plays a great role in the correct understanding of projectile motion due to the vector nature of its kinematics quantities (Hidayatulloh et al., 2021). For example, the graphical representation of acceleration and velocity gives a quick visualization of their variations in both vertical and horizontal components for projectile motion (Vaara & Sasaki, 2019). Moreover, the use of graphs to represent motion helps to determine certain kinematics quantities and plays an alternative role to the use of equations, which may seem difficult to students (Amin et al., 2020).

The inability of the students to distinguish between the signs of upward and downhill directions or left and right directions is one of the reported students' challenges for graphical representation in kinematics (Eriksson et al., 2022; Mudau, 2014). According to custom, the upward and the downward directions are considered positive and negative directions, respectively. Nonetheless, it was found that 39.5% of 76 high school students in an Indonesian study that examined students' beliefs about how projectile motion is depicted graphically and is calculated the acceleration of gravity as a positive value rather than a downward constant vector (Hidayatulloh et al., 2021). A portion of the velocity-time graph for the vertical component lies in the upper positive region, and a portion lies in the lower negative region. The proper comprehension of signs on either side can aid in comprehending the actual motion of the object. Yet only 32.0% of students in the study, which aimed to examine their comprehension of free fall motion, could distinguish between the uphill and downward part of a velocity-time graph (Rane, 2015).

The gap in students' graph skills has also been linked to their knowledge of about four operations including reading graph coordinates, determining the slope and area under graphs and connecting representations (Ivanjek et al., 2016; Phage et al., 2017; Susac et al., 2018). For example, students need to clearly understand that the slope of position-time and velocity-time graphs represent the concept of velocity and acceleration respectively (Mazibe et al., 2020). During this process, students must identify the kinematics variables represented on the two axes of the graph and determine the kinematics quantity from the gradient accordingly. However, some students may fail to read the correct scale of a physical quantity on the axis of a graph and thus fail to calculate the correct slope (Amin et al., 2020). This problem was revealed when students were asked to compare the position-time graph and velocity-time graph for a uniform velocity linear motion (Núñez et al., 2022). In fact, only 28.9% of 76 secondary students realized that the slope of the position-time graph meant the constant velocity. Other graph skills have been studied in the research conducted on learners' conception of vertical projectile motion (Chinorumba, 2017). In this study, students were tasked to identify the initial velocity from a velocity-time graph for vertical projectile motion and results showed that students had good graph reading skills with above 70.0% giving correct responses. However, this students' performance was not just a common consideration. Rather, it was linked to the fact that concerned students had graphical work in other courses like mathematics.

Linking conceptual learning and graph skills is compulsory in projectile motion. For example, the phenomenon-based experiential learning has helped students to shift from wrong conception of varying acceleration and have a correct scientific conception that projectile motion occurs under constant acceleration due to gravity (Yuliati et al., 2020). However, the use of PhET simulation activities was very effective in helping students to learn kinematics quantities on two independent axes (Chinaka, 2021). On the other side, Hidayatulloh et al. (2021) found that a low performance in graphical representation, 55.5% of 76 students in one high school in Indonesia, was linked to misconceptions about velocity vector. In another, it was found that 40.0% of 305 students believed that the acceleration at the maximum height of a projectile becomes zero (Zaid & Zainuddin, 2017), which indicated a confusion between the concept of velocity and acceleration. Aslan and Buyuk (2021) claim that traditional teaching cannot eradicate misconceptions in projectile motion. Further, Duijzer et al. (2019) emphasize that the simultaneous graphical representation and presentation of the corresponding real motion helps students to acquire motion graph skills. This was seen as an effective strategy for improving students' learning and it can be achieved when the teaching and learning environments are set in the form of augmented reality.

THEORETICAL FRAMEWORK

In accordance with the experiential constructivist learning theory, the predict-observe-explain (POE) technique was employed in the current study. The constructivism learning theory is a theory in which the learning process is perceived as a process, where students construct new knowledge based on prior knowledge through the exposed new learning experience (Karwasz & Wyborska, 2023; Nurpatri et al., 2021; Sunzuma et al., 2022). POE model was developed by two constructivist Australian researchers, Richard White and Richard Gunstone, in the years of 1992 (Vaara & Sasaki, 2019) as a new version of demonstrate-observe-explain (DOE). This strategy opens active learning opportunities for students (Banawi et al., 2019; Karamustafaoglu & Mamlok-Naaman, 2015; Latifah et al., 2019; Yuenyong & Yuenyong, 2021).

MATERIALS AND METHODS

Research Design and Study Settings

In this study, a quasi-experimental design comprising an experimental group and a control group was used. For the experimental group, the intervention incorporated projectile motion PhET and projectile motion GeoGebra simulation activities adopted from https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html and https://www.geogebra.org/. During two weeks, each group received the teaching of projectile motion in four lessons but for the control group, only traditional methods were used. The learning material comprised the content and learning activities about projectile motion reflecting the learning objectives prescribed in the curriculum, which include the graphical skills on projectile motion. The learning activities were related to the following lessons:

1. Definition of projectile motion and related terms
2. Applications of projectile motion
3. Graphs of projectile motion
4. Expressions of projectile motion

Sample and Sampling Procedure

The sample of this study comprised of 54 students from two public secondary schools in two different sectors. They were enrolled in the combination of physics-chemistry and biology (PCB). The selection of these schools was purposively based on their category (public and gender-mixed), availability of computer labs and easy access to participants. Students who completed both pre- and post-test were 37 in the experimental group whereas the control group had 17 students.

Data Collection Methods and Instrument

In this study, a multiple-choice test on projectile motion graphs was given to students on pre- and post-test occasions using a paper-and-pencil format. The test had 10 items that covered the ability to depict projectile motion graphically. The following categories of questions aimed to test students' comprehension of projectile motion graphs:

- position vs. time graphs (questions: 1, 3, 4, 7, and 10)
- velocity vs. time graphs (questions: 2, 5, and 9)
- acceleration vs. time graphs (questions: 6 and 8)

The instrument's components were created in accordance with the projectile motion learning objectives outlined in the curriculum. One of the learning outcomes for this unit is to divide projectile motion into vertical and horizontal components and connect the two using linear motion graphs. The instrument's aim was to identify any problems for understanding position, velocity, and acceleration versus time graphs.

Data Analysis Procedures

First of all, to assess the extent to which students responded correctly on each test item, frequencies of correct responses were recorded and expressed in percentages using the Google sheet. Secondly, the normalized learning gains for both groups were calculated from the individual learning gains. This was done using the following formula:

$$g_{av} = \langle \frac{\%\ in\ posttest - \%\ in\ pretest}{100 - \%\ in\ pretest} \rangle.$$

Thirdly, t-tests were used to compare the normalized learning gains between groups and with the minimum learning gain for the medium range.

RESULTS

Students' Scores on Each Test Item

To account for the research objective, it was first necessary to assess students' understanding of graphs for individual test items. Percentages of each choice on Q2 and Q5 were particularly considered. Q2 was a question asking students to relate the velocity-time graph for a projectile motion to the real movement of the object that goes up and down in air. On the other hand, Q5 served to ask students to choose the correct value of the acceleration from the given velocity-time graph for a ball fired in air. The corresponding results in both groups are presented respectively in **Figure 1** and **Figure 2**.

Figure 1 shows that in the experimental group, the highly scored items are Q3 and Q8 in the pre-test with 20 out of 37 participants, which is equivalent to 54.05% whereas the lowly scored are Q6 and Q9 with two out of 37 participants giving 5.41%. Question Q3 required students to choose the correct vertical displacement-time graph, among four graphs, which corresponds to the projectile motion of a ball fired in air at an angle. Further, in Q8, the students were asked to choose the correct acceleration-time graph among four graphs for a horizontal movement of the ball fired vertically upwards. Furthermore, Q6 was testing students' understanding of graph of vertical acceleration for a projectile whereas Q9 intended to test students' ability to calculate the area under the velocity-time graph and to relate it to the distance moved.

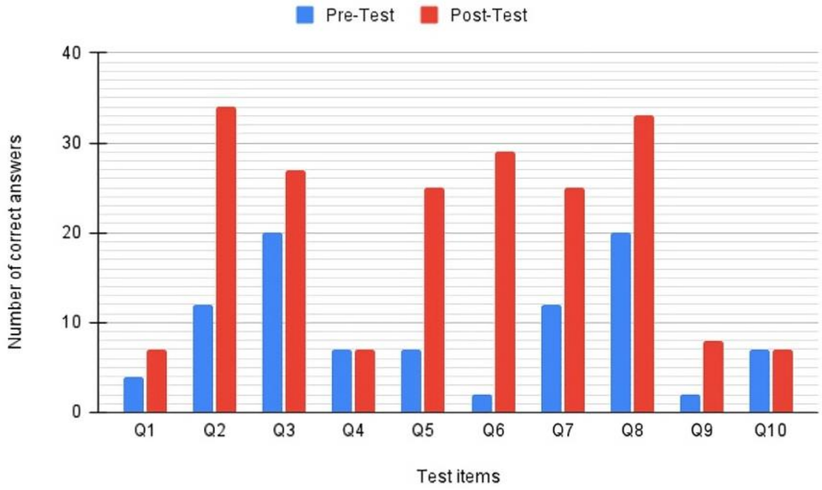

Figure 1. Correct answers for each test item in the experimental group (Source: Field data, 2022)

On the other hand, it is seen that in the post-test Q2 was highly scored with 34 out of 37, which gives 91.90% whereas Q1, Q4 and Q10 all got seven correct answers, which is equivalent to 18.92%. The biggest increase in number of correct answers between pre- and post-test is observed on Q6 with an increase of 72.97% whereas the smallest is on Q4 and Q6, where there is no change. For these items, Q1 served to uncover students' skills on reading the time coordinates for maximum height of a vertical projectile, from the vertical distance-time graph, for them to calculate the corresponding initial velocity whereas Q4 asked students to identify a correct position-time graph for the horizontal motion of a projectile under the influence of air resistance. Moreover, Q10 asked students to choose the kinematics quantity graphed versus time for a graph showing a positive curve in the free fall part of a projectile motion.

As it was observed from answers of different students in the pre-test on the test item Q2, some students (35.14%) confused the graph and the real motion of the object in projectile motion saying that it was moving down in air as the graph has a negative slope. However, after the intervention this percentage was reduced to 5.41% in the post-test meaning that many students changed their minds to the real meaning of the graph. On the other hand, the pre-test showed that students' ability to determine the slope of the velocity-time graph, Q5, was not enough. 48.65% of students found the correct value of acceleration due to gravity with incorrect sign whereas 18.92% did it well on the value and sign. Other students simply read the coordinates on the vertical and confused the values of velocity and acceleration. After the intervention, the post-test indicated that the answers for the correct value increased to 67.57% whereas the other side decreased to 18.92%.

Figure 2 shows that students' understanding of graphs of projectile motion on each individual test item for control group is different than that for experimental group. It can be observed that the biggest increase in number of correct answers is on Q5, where it changed from two students in the pre-test to 14 students in the post-test and this is equivalent to the increase of 70.59%. On this question, the pre-test indicated that many students were not able to determine the slope, 41.18% chose wrong value and 29.41% chose the value with wrong sign. Students answered the question by reading the coordinates on the velocity-time graph. However, the post-test in the control group showed that almost all students (82.35%) changed their minds to the correct answer. Unfortunately, a surprising decrease in the number of correct answers was observed on Q2, (11.75%). In the pre-test it was seen that a big number of students in the control group, (47.06%), confused the velocity-time graph and the actual projectile motion it represents saying that the object was moving down in air whereas 41.18% correctly answered the question.

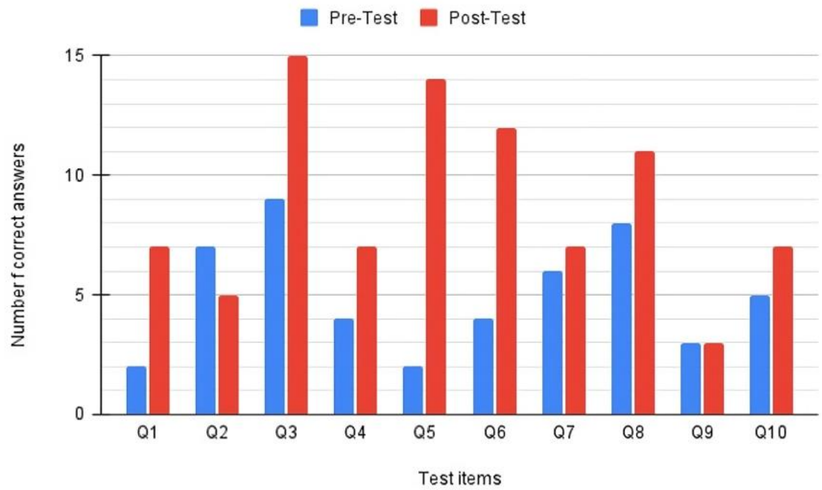

Figure 2. Correct answers for each test item in control group (Source: Field data, 2022)

The post-test showed that students were not able to interpret the same graph. Correct answers decreased to 29.41%. The highly scored test item was Q3 on both occasions with nine and 15 correct answers (2.94% and 88.24%) in pre- and post-test respectively. On the other hand, the lowly scored items are Q1 and Q5 with two correct answers (11.77%) in the pre-test and Q9 with three correct answers (17.65%) in the post-test.

Improvement in the Understanding of Graphs of Projectile Motion in Each Group

It was first necessary to compare the improvement in understanding of graphs of projectile motion for both groups with the standard categories of normalized learning gain in order to determine how much computer-simulated teaching tools influence senior four students' understanding of graphs of projectile motion in comparison to the traditional teaching methods. The one-sample t-test in SPSS was run along with the calculation of the normalized learning gains in both groups. The experimental and control groups' normalized learning gains were found to be 0.39±0.14 and 0.33±0.07, respectively. **Table 1** and **Table 2** show the outcomes for one-sample t-tests.

Table 1 shows that the normalized learning gain in the experimental group was statistically significantly greater than the test value of normalized learning gain, t(36)=3.944, p<0.01.

Table 1. One-sample t-test for normalized learning gain in the experimental group (test value=0.3)

	t	df	Sig. (2-tailed)	Mean difference	95% confidence interval of difference	
					Lower	Upper
N-gain	3.944	36	.000	.0886	.0430	.1342

Although from **Table 1** it was observed that it is greater, from **Table 2** it is seen that the mean learning gain in the control group (0.33±0.07) is not statistically significantly greater than the test value of learning gain, t(16)=1.788, p>0.05.

Table 2. One-sample t-test for normalized learning gain in the control group (test value=0.3)

	t	df	Sig. (2-tailed)	Mean difference	95% confidence interval of difference	
					Lower	Upper
N-gain	1.788	16	.093	.0283	-.0053	.0618

Comparing Normalized Learning Gains for Both Groups

To examine the learning gains in comprehending graphs of projectile motion between two groups, an independent-samples t-test was used. **Table 3** displays the comparable outcomes.

Table 3. Independent-samples t-test of normalized learning gains between two groups

		Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	t	df	S2T	MD	SED	95% CI of difference	
									Lower	Upper
N-gain	Equal variances assumed	4.501	.039	-1.725	52	.091	-.0603	.0350	-.1305	.0100
	Equal variances not assumed			-2.194	51.860	.033	-.0603	.0275	-.1154	-.0052

Note. CI: Confidence interval; S2T: Sig. (2-tailed); MD: Mean difference; & SED: Standard error difference

The independent-samples t-test with equal variances not assumed is required by the Levene's test of equality of variances, according to **Table 3** (p=0.039). Therefore, **Table 3** demonstrates that the experimental group's normalized learning gain on understanding graphs of projectile motion (0.39±0.14) is statistically significantly higher than the control group's normalized learning gain on understanding graphs of projectile motion (0.33±0.07), t(52)=-2.194, p=0.033.

DISCUSSION OF FINDINGS AND CONCLUSIONS

This study intended to answer the question: To what extent do computer-simulated teaching tools influence senior four students' understanding of graphs of projectile motion in comparison with the traditional method?

Students' Understanding of Graphs on Individual Test Items

The test items of the research instrument were based on displacement-time graphs, velocity-time graphs and acceleration-time graphs. As it is presented in **Figure 1** and **Figure 2**, the number of correct answers for students on individual graphs has increased in both groups except on item 4 and item 10 in the experimental group and item 2 and item 9 in the control group. The biggest increase in correct responses from pre- to post-test was observed on test items Q6 in the experimental group and Q5 in the control group. First of all, Q6 required students' ability to interpret graphical representation of the vector vertical acceleration in projectile motion. A similar result was noticed in a recent study on the acquisition of projectile motion concepts on phenomenon-based physics' experiential learning (Yuliati et al., 2020). In fact, using the PhET and GeoGebra, students were able to experiment and visualize the vector components of velocity and acceleration.

A surprising result was observed on test item Q2 in the control group. This item indented to measure student ability to relate the velocity-time graph and real projectile motion. Although this question was among well performed test items in the pre-test for the control group, it showed a decline of 11.75% in the post-test whereas correct responses increased by 59.46% in the experimental group. Moreover, the pre-test showed a common misconception of confusing a graph with the real motion, which is among main students' difficulties on motion graphs interpretation (Vaara & Sasaki, 2019). 35.14% in the experimental group and 47.06% answered that the object was moving down in air as the straight line was in a negative slope. A change in students' thinking on the same question has been observed, where for the control group students still struggled to relate the velocity-time graph and the real projectile motion whereas for the experimental group the percentage of that confusion reduced to 5.41% and correct answers increased by 91.89%. These results indicate that using PhET and GeoGebra simulation tools has allowed students to overcome the difficulty of viewing graphs of motion as pictures of motion whereas students in the control group the traditional method did not tackle the problem.

Improvement of Students' Understanding of Graphs of Projectile Motion in Each Group

Since the teaching intervention was different in both groups, it was necessary to assess the extent to which students improved their understanding of graphs of projectile motion in each individual group. The results in **Table 1** indicate that the normalized learning gain in the experimental group (0.39±0.14) is in the moderate range $t(36)=3.944$, $p<0.00$. The normalized learning gain in the control group (0.33±0.07) seen in **Table 2** is in the low category, $t(16)=1.788$, $p>0.05$. These results reflect the learning process in each group. In the experimental group, with the learner-centred techniques, students were assisted to investigate the variation of acceleration, velocity and displacement vectors by manipulating different variables like the angle of projectile and the type of projectile. Since students had the opportunity of replaying the simulations for their inquiry and verification, their overall understanding of graphs of projectile motion improved. However, there are other similar studies which reported higher values of normalized learning gain (Subali et al., 2017; Yuliati et al., 2020). This difference can be associated with the mathematical background of students and the available free time to revisit the computer labs.

Actually, students in PCB learn mathematics as a minor subject. On the other hand, students used the computer labs in regular classroom sessions only. In contrast, students in the control group were not exposed to the experiential learning process hence affecting their understanding of graphs of projectile motion.

Comparing Normalized Learning Gains for Both Groups

The results were summarized in **Table 3** and show that the normalized learning gain in the experimental group (0.39±0.14) is statistically significantly greater than the normalized gain in the control group (0.33±0.07), $t(52)=-2.194$, $p=0.033$. In general, these results reveal that students in the experimental group improved their understanding of graphs of projectile motion better than those in the control group. Results reflect students' opportunities in the experimental group compared to control group. The use of PhET and GeoGebra simulations activities with the POE strategy allowed students to meaningfully connect their conceptual understanding of two-dimensional kinematics quantities and their graphical representation.

Our results are consistent with the findings of the study conducted in Turkey to investigate the effect of GeoGebra on conceptual change in projectile motion (Aslan & Buyuk, 2021). In this study, it was recorded that the use of GeoGebra has positively eradicated the misconceptions related to velocity and acceleration. Moreover, similar findings were found while investigating the effects of an integrative learning model on grade 12 learners' conception of vertical motion (Chinorumba, 2017). The results of the current study are also consistent with Chinaka's study, which considered how PhET affected South African pupils' comprehension of concepts of projectile motion (Chinaka, 2021). Similar to our study, PhET and GeoGebra are identified as effective active learning tools in high school science teaching (Banda & Nzabahimana, 2023; Rahmawati et al., 2022; Solvang & Haglund, 2021). Moreover, this study complements the recommendations that African physics teachers should use computer simulations to promote inquiry-based learning through experimentation (Akuma & Callaghan, 2019; Beichumila et al., 2022; Ouahi et al., 2022).

Limitations of the Study

This study was carried out in a Rwandan setting, where teaching and learning of projectile motion had not been the subject of study before. Because of this, the researchers were unable to compare the study's findings to the situation in Rwanda. In addition, it was correctly asserted, in line with the literature, that students' understanding of graphs of motion is significantly influenced by their mathematical background. Participants who are enrolled in mathematics major options might have been considered, adding another layer of interpretation to the study's conclusions. Finally, it was discovered throughout the intervention that the computer-simulated teaching tools were used during the regular classroom sessions only, which may have had an impact on our findings for the experimental group.

Conclusions

The aim of this study was to assess the extent to which computer-simulated teaching tools influence Rwandan senior four students' understanding of graphs of projectile motion in Rwamagana district. The results indicated that students who learned projectile motion with the help of computer-simulated teaching tools demonstrated their understanding of graphs of projectile motion better than those who used traditional methods.

The findings of the current study recommend for physics teachers the use of PhET and GeoGebra simulations in their teaching of projectile motion, to help learners analyse critically vector quantities. Teachers should also consider the students' independent learning.

Similar studies, which can consider a large sample in the Rwandan context on the use of PhET and GeoGebra in teaching projectile motion and involving students with mathematics major are recommended.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: This article was funded by African Center of Excellence for Innovative Teaching and Learning Mathematics and Science.

Ethical statement: Authors stated that the study was approved by Research and Innovation Unit at University of Rwanda on 14 February 2022.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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