Website:www.jriiejournal.com ISSN 2520-7504 (Online) Vol.7, Iss.1, 2023 (pp. 123 - 132)

Use of Physics Education Technology (PHET) Simulations to Enhance Students' Achievement in Bivariate Statistics within Selected Secondary Schools of Muhanga District, Rwanda

Uwimana Jerome and Mugabo Rugema Leon
African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), College of Education, University of Rwanda
Email: uwjeron@gmail.com

Abstract: *This quasi-experimental research was conducted to examine the effects of using Physics Education Technology simulations on students' achievement in bivariate statistics within selected secondary schools of the Muhanga District of Rwanda. This paper reports results from experimental study details on the use of Physics Education Technology simulations to enhance students' achievement in bivariate statistics. Two classes of students from senior five, who have mathematics as a core subject, selected from two schools participated in the study. One class was the control group which was taught using the conventional teaching method while another class was the experimental group which was taught using the conventional teaching method supported by Physics Education Technology simulation activities. The main instrument used to gather information was mathematics assessment pre-and post-tests administered before and after the intervention. The study showed that students improved their achievement on bivariate statistics after their exposure to PhET simulations and conventional teaching methods. Significant differences from their pre-test and post-test scores were found for both groups. It was found out that there was no significant difference between the PhET simulations and conventional teaching method pre-test scores means whereas there was a significant difference in their post-test score means. This study found that the use of Physics Education Technology simulations in learning bivariate statistics can improve the students' achievement.*

Keywords: *PhET simulations, conventional teaching, bivariate statistics, teaching methodology, students' achievement, pre-test, post-test*

How to cite this work (APA)

Uwimana, J. and Mugabo, R. L. (2023). Use of Physics Education Technology (PHET) Simulations to Enhance Students' Achievement in Bivariate Statistics within Selected Secondary Schools of Muhanga District, Rwanda. *Journal of Research Innovation and Implications in Education, 7*(1), 123 – 132.

1. Introduction

Rwanda has adapted and started to implement a new curriculum that expects teachers to utilize computer technology as an instructional tool to assist students to learn mathematics and other subjects (Rwanda Education Board [REB], 2015) since 2016 until now. For this reason, the government of Rwanda through the Ministry of Education and other stakeholders are distributing ICT tools including computers, projectors, and internet connectivity in secondary schools to implement the program of smart classrooms to ensure a high-quality of teaching and learning any subject (Ministry of Education [MINEDUC], 2016). The integration of ICT in teaching helps students learn mathematics to further visualize the mathematical abstracts including the graphs.

Mathematics is considered difficult for students to learn because some of its concepts are abstract in nature and require visualization to further understanding (Martinez-Sierra, &Miranda-Tirado, 2015). It is the most challenging and problematic subject in the educational aspect. Although mathematics is difficult for students to learn, it is one of the most important areas of science because mathematical skills and knowledge are very important in daily life. It plays a vital role in society by enhancing students' thinking logically, abstractly, and critically (Ukobizaba, Ndihokubwayo, Mukuka & Uwamahoro, 2021).

Mathematics is a basic tool for analyzing concepts in every field of human endeavor (Christy, 1993). Educational computer simulation programs are one which help students learn mathematics easily. Through educational computer simulation programs, students understand some mathematical abstract concepts and relate them to real-life situations easily. Educational computer simulation programs are considered to be one of the best and most powerful educational computer programs when used in science education if properly programmed. It is based on the principle of constructivist philosophy, which emphasizes that the students learn through scientific experience; these are also computer-generated dynamic models, which can explain the concept or simplified model of a component, of a phenomenon, or a conceptual process in the real world, consisting of animation, visualization, and interactive laboratory experiences (Ouahi, Bliya, Hassouni & Ibrahim, 2021). Computer technology could be used to attempt to find the solution to this problem.

The visualization of abstract concepts in mathematics especially graphs helps students use observation skills, analysis, and conclusions. With the visual presentation, students build connections among selected images to create a coherent pictorial model in working memory. They develop an understanding of some abstract concepts. Manipulatives and other representations offer powerful support for Students, which may be gradually internalized as mental images take over (Carbonneau, Marley & Selig, 2013; Streefland, 1991). Students learn meaningful information and ideas when they work through tutorials and interact with computer simulations (Arends, 2012).

Many schools in Rwanda use a conventional teaching approach in teaching bivariate statistics. Studies argued that the conventional teaching approach is not sufficient for students to be more competent in bivariate statistics. It does not provide clear graphs for students to further understand abstract concepts. To support the conventional teaching approach, the University of Colorado Boulder in the United States of America initiated the Physics Education Technology (PhET) project that has designed a suite of free interactive simulations for teaching mathematics and sciences.

The PhET simulations could be used to help students understand abstract concepts in mathematics through visualization and presentation. The PhET simulations visualize the graphs clearly and engage students to manipulate activities adequately which requires the graphs. The PhET simulations support students to link the phenomena of real-life situations and knowledge.

Studies have argued that the use of PhET simulations coupled with teacher facilitation and activity sheets that engage students in mathematical ideas can result in effective lessons incorporating technology (Hensberry, Moore & Perkins, 2015) and another study concluded that Physics Education Technology interactive simulation strategy can improve the students' performance (Taneo & Moleño, 2021). This study is therefore worthy to investigate the effects of using Physics Education Technology simulations on students' achievement in bivariate statistics within selected secondary schools of the Muhanga District of Rwanda. The specific objectives of this study are:

1. To examine the significant difference between the pre-and post-tests scores of the control group and the experimental group
2. To assess the impact of the use of PhET Simulations on students' achievement in bivariate statistics.

2. Literature Review

2.1 Teaching and Learning Statistics

Statistics is the science of collecting, organizing, analyzing, and interpreting data to make conclusions. There are two main branches of statistics namely descriptive statistics and inferential statistics. Descriptive statistics is the branch of statistics that involves the organization, summarization, and display of data while inferential statistics is the branch of statistics that involves using a sample to draw conclusions about a population (Larson & Farber, 2012). Teaching statistics enables students to leave the classroom with a basic understanding of statistical concepts and methods as well as the ability to apply these methods to new problems and settings.

2.2 Using Simulation to Teach and Learn Statistics

In teaching statistics, it is important to both model the use of technology as a problem-solving tool and to take advantage of the ability to automate calculations and graphics, facilitate explorations of statistical concepts through dynamic, interactive, visual environments, and experience first-hand the stochastic nature of statistical processes. The impact of technology on the teaching of statistics has reached all grade levels. One of the most challenging aspects of teaching and learning statistics is that so many statistical concepts and methods are based on the issue of what would happen if a random process (such as random sampling from a population or random assignment of subjects to treatment groups) were repeated indefinitely. This abstract notion is very difficult for most people to grasp. Technology provides the opportunity to make this abstract idea more concrete by enabling students to repeat such random processes in a large number of times and describe their observations firsthand. Mills (2002) provides an overview of using computer simulation methods to teach statistics, though empirical research in statistics classrooms has been limited. Research in other fields, particularly in educational technology, has suggested several guidelines for using simulations in instruction.

2.3 Teaching and Learning Bivariate Statistics

In teaching and learning bivariate statistics, technology plays a vital role in the production of complete scatter graphs. Students can focus on interpretation rather than focusing on graphing. They are encouraged by the complete image to take a holistic view of the graph (Ainley, Pratt & Nardi, 2001). Technology use can support students at a higher level of understanding the availability of linked representations (data and summary statistics, movable lines and their equations, residuals, and the sum of the squares). It can also help students manipulate data and the lines on scatter plots, and the production of regression models on scatter plots (Forster, 2007).

2.4 Teaching with PhET Simulations

PhET Sims are intentionally designed to be intuitive, flexible tools and can be integrated into instruction in many ways: as part of a student-centered lesson; as a pre-class activity; as a post-instruction assignment; or in conjunction with traditional concrete manipulatives to name a few (Hensberry, Moore & Perkins, 2015). Most of the learning occurs when students are asking themselves questions that help them explore the simulation and discover the solutions. They learn better when they engage themselves in such exploration (Wieman, Adams & Perkins, 2008). Similarly, to build on Students' intuitive understandings of situations, diagrams and models can be more powerful ways of approaching mathematical problems (Nunes & Bryant, 2009). In PhET classes, the teacher manipulated PhET Sims activities using a projector. During the simulations, teachers ask questions, and students answer using what they already knew and what they have seen on the screen (Ndihokubwayo, Uwamahoro & Ndayambaje, 2020).

2.5 Impact of Physics Education Technology on the Performance of Students

A study on learning argues that students learn better when they construct their own understanding of scientific ideas within the framework of their existing knowledge. To achieve this process, students should be motivated to engage with the content actively and should be able to learn from that engagement effectively (Wieman, Adams & Perkins, 2008). Computer simulations help students understand mathematical concepts; manipulate variables; use a variety of representations including graphs, pictures, animations; vectors, and numerical data displays which help them understand the underlying concepts, relationships, and processes; explore approaches to occurrences that are hard to experience in a classroom or a laboratory; and demonstrate their portrayal and mental models of the physical world (Garcia, 2020). Many studies found the use of PhET Sims in teaching science lessons effectively. The University of Colorado Boulder showed that there are lessons in Mathematics such as arithmetic, calculus graph, equation graph, build a fraction, area builder, area model algebra, area decimals, area model multiplications, graphing lines, graphing slope intercept, fraction matcher, and other PhET Sims. The studies found that there is an increase in the academic performance of the students after their exposure to interactive simulations (Davis, 2007). PhET Sims give students concrete on how Sims work and to think like a scientist doing scientific work. They help them understand bivariate statistics more interactively. Through the use of PhET Sims, teachers' methodology becomes more advanced and inclined with the use of technology, and classroom discussions are more interactive and efficient for both students and teachers. In more developed countries like the USA, Japan, Australia, and other school administrators provide an in-depth understanding of how simulations work inside classroom discussions. This methodology may serve as an example to the officials of the department of education particularly school administrators to incorporate more simulations in teaching different subjects like mathematics, science, or physics (Garcia, 2020). PhET Sims helps students interact with each other through sharing experiences including reflecting and creating unique opportunities for whole-class discussions.

2.6 Theoretical framework

This study is supported by the cognitive theory of multimedia learning. Students learn more deeply from words and pictures than from words only (Mayer, 2005). Learning with a combination of words and pictures helps students connect words and pictures meaningfully and they learn deeper than they learn with words or pictures only. One aim of the cognitive theory of multimedia learning is to encourage students to build mental presentation from the presented material coherently. The task of students is to participate actively and construct their own knowledge effectively.

The cognitive theory of multimedia learning is based on three cognitive science principles of learning namely the human information processing system includes dual channels for visual or pictorial and auditory or verbal processing. Each channel has a limited capacity for processing and active learning entails carrying out a coordinated set of cognitive processes during learning. In the first principle, through illustration, information is presented to the eyes. Students begin by processing that information in the visual channel and when information is presented to the ears, students begin by processing that information in the auditory channel.

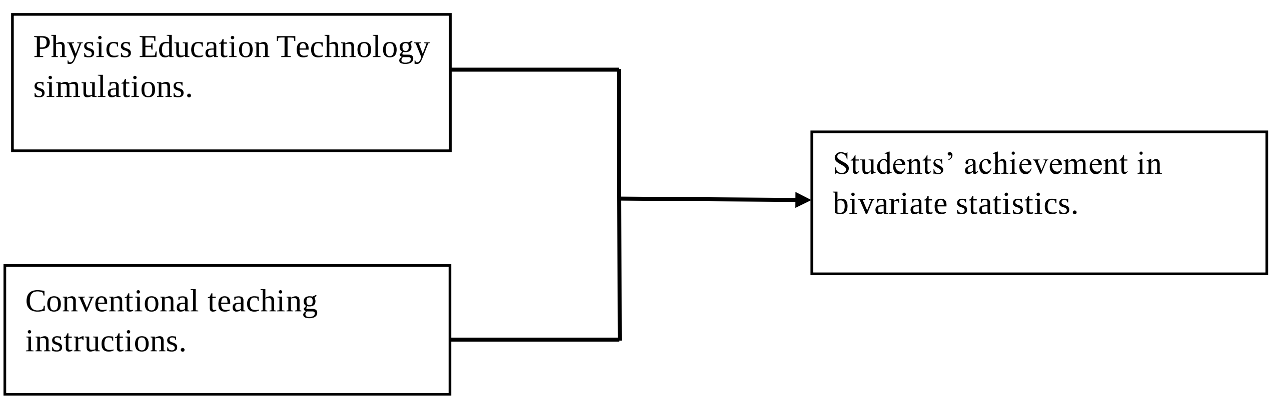
The second principle is that students are limited in the amount of information that can be processed in each channel at one time. Students can hold only a few images in working memory at any one time, reflecting portions of the presented material rather than an exact copy of the presented material when an illustration is presented well.

The third principle is that students actively engage in cognitive processing to construct a coherent mental representation of their experiences (Mayer, 2005). In this study, students studied bivariate statistics through visualization and illustration using PhET simulations. They manipulated simulations to further understand bivariate statistics.

2.7 Conceptual framework

This study tried to examine the effect of the use of PhET Sims to enhance students' achievement in bivariate statistics. Two groups were involved in this study: the control group and the experimental group. In this study, the independent variables were the use of PhET Sims as an instructional aide in teaching bivariate statistics for the experimental group and teaching bivariate statistics for the control group with the conventional teaching method.

PhET can be used in teaching Mathematics meaningfully (Perkins, 2015), whereas the conventional teaching method includes the use of a board and chalkboard for teachers and pen and paper for all students. In this study, both groups were taught the same lessons. These include the covariance of the two variables, the correlation coefficients between the two variables, and the linear regression lines. The dependent variable is the students' achievement in bivariate statistics based on the mean gain scores of both groups.



Conceptual Framework

2.8 Research Problems

This study examined whether the PhET Sims can help senior five students improve their overall achievement in bivariate statistics. More specifically, it seeks answers to the following questions:

i. Is there a significant difference between the mathematics assessment pre-test scores of the control group and the experimental group?
ii. How do PhET simulations impact the students' achievement in bivariate statistics?

2.9 Research hypotheses

There is no statistically significant difference between the mathematics assessment pre-test scores of the control group and the experimental group.

There is no statistically significant difference between the achievement of students exposed to PhET Simulations and Conventional Instruction regarding post-test scores.

3. Methodology

3.1 Research Design

The research design is the plan, structure, and strategy of investigation conceived to obtain answers to research questions and control variance (Creswell, 2003). This study used a quasi-experimental design to find out the effects of using Physics Education Technology simulations on students' achievement in Bivariate Statistics. It used two whole classes selected from two schools to gather information. This study also employed a quantitative research approach to examine, through experimental research, the effects of using Physics Education Technology simulations on students' achievement in bivariate statistics. This approach compared the achievement of students who were taught by the conventional teaching method supported by Physics Education Technology simulations and those who were taught by the conventional teaching method only.

3.2 Participants

The participants of this study were senior five students with mathematics as a core subject from the selected schools. They were grouped into two groups namely the control group and the experimental group.

3.3 Sample and Sampling Technique

A sample size of items is to be selected from the entire population to constitute a sample (Kothari, 2004). This study aims to examine, through experimental research, the effects of using Physics Education Technology simulations on students' achievement in bivariate statistics. In this study, two schools were selected to compare the achievement of students in bivariate statistics. One school was selected as the experimental group since it had adequate resources to facilitate this research while another school was selected as the control group. There were 35 senior five students in the experimental group and 45 students in the control group.

Sampling is the process of selecting the individuals who will participate in a research study (Fraenkel, Wallen & Hyun, 2012). The sample of this study consisted of 80 students from senior five students, who learn Mathematics as a core subject, in two selected schools. 35 students were from the experimental group while 45 students were from the control group.

Students of the experimental group were taught with the assistance of Physics Education Technology simulations, while students of the control group were taught using the conventional teaching method only. This study used a purposive sampling method to select the participants based on the adequate ICT facilities that make this study effective. Another reason to use the purposive sampling method was the issue of time management to intervene in different schools at the same time because bivariate statistics is one of a couple of the last units among the units that are supposed to teach in senior five. Bivariate statistics is supposed to be taught at the same time in the same week. Also, those schools are close to each other.

3.4 Instruments

Data was collected using the mathematics assessment pre- and post-tests. The researcher administered the mathematics assessment pre-test to both groups to access the students' prior knowledge gained in statistics in senior four. The mathematics assessment pre-test was done by the experimental group and the control group before learning bivariate statistics. It was formulated according to students' prior knowledge about the statistics content acquired in senior four because students need them to further understand bivariate statistics. Then, students started learning bivariate statistics.

In teaching bivariate statistics, the researcher employed various PhET simulation activities in presenting the lessons and exploration of activities conducted along with the visual aids available. This is done online or offline for free from the PhET simulations website. In this study, PhET simulation activities were used to help students visualize regression lines, and coefficient of correlation and explore the effect of many different parameters embedded in the simulation. After accomplishing all the lessons included in the study, the researcher administered the mathematics assessment post-test to both groups. It was about the mathematical knowledge gained during the lessons. Both, mathematics assessment pre-and-post tests, had the same number of questions and approximately the same kind of questions.

3.5 Procedure

This study used two groups: the Control group and the Experimental group. Both groups were given a pre-test to assess the students' prior knowledge acquired in statistics in senior four. The control group was taught lessons of bivariate statistics using the conventional teaching method only while the experimental group was taught the same lessons supported with PhET Sim activities. During the lessons, the students of both groups studied how to find the covariance between two variables, Pearson's coefficient of correlation, the regression lines, and interpretations. Both groups were given mathematics post-test to determine the effect of the use of PhET Sims in teaching bivariate statistics on students' achievement. The data collected was analyzed by t-test through Statistical Package for the Social Science (SPSS) version 20. This study employed a statistical t-test to test the difference between the means of the two groups to examine the effects of using Physics Education Technology simulations on students' achievement in bivariate statistics. To determine whether there is a significant difference between mathematics assessment pre-test scores of the control group who was exposed to the conventional teaching method and the experimental group who used the PhET sim activities, a T-test for independent samples was used because the researcher wanted to test the difference between means for two samples which are not related. T-test for the independent samples was also used to determine whether there is a significant difference in the mean gain scores between mathematics assessment post-test scores of the control group and the experimental group. All tests were done at a 0.05 significance level.

4. Results and Discussion

4.1The difference in the pre-test scores of the control group and the experimental group

Table 1 presents the descriptive statistics that compare the mathematics assessment pre-test mean scores of the control group and the experimental group. T-test for independent samples was used to compare the significant difference between mathematics assessment pre-test scores to determine whether the students in the control group and the experimental group are equivalent in bivariate statistics at the start of the study.

Table 1: Difference in the pre-test scores of the control group and the experimental group

Group Statistics

	Groups	N	Mean	Std. Deviation	Std. Error Mean
Pre-Test	Experimental Group	35	61.74	14.61	2.47
	Control Group	45	61.07	15.87	2.37

Independent Samples Test

		t-test for Equality of Means				
		T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Pre-Test	Equal variances assumed	.196	78	.845	.67	3.46
	Equal variances not assumed	.198	75.732	.844	.67	3.42

The pre-test means score in the control group ($M = 61.07$) is slightly less compared to the experimental group ($M = 61.74$) with a difference of 0.67. The distribution of scores around the mean score is slightly higher in the control group ($SD = 15.87$ and $SE = 2.37$) compared to the experimental group ($SD = 14.61$ and $SE = 2.47$). Using the t-test for independent samples, sig. is 0.84 which is higher than 0.05. This shows that there is no significant difference between the mathematics assessment pre-test scores mean for both groups. This means that at the start of the study, the students in the control group had similar knowledge of bivariate statistics as that of the experimental group. Hence, the two groups were equivalent before the start of the study.

4.2 The difference in the pre-and post-test scores of the control group and the experimental group

This study also attempted to determine whether there is any significant difference between mathematics assessment pre-and post-tests scores of the experimental group and the control group. To do this, a t-test for independent samples was used to compare the mathematics assessment pre-and post-tests scores mean of the control group and the experimental group. Table 2 shows the results.

Table 2: Difference in the pre-test and post-test mean scores of the control group and the experimental group

Group Statistics

	Groups	N	Mean	Std. Deviation	Std. Error Mean
Pre-Test	Experimental Group	35	61.74	14.61	2.47
	Control Group	45	61.07	15.87	2.37
Post-Test	Experimental Group	35	72.51	17.80	3.01
	Control Group	45	64.38	13.87	2.07

Independent Samples Test

		t-test for Equality of Means				
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Pre-Test	Equal variances assumed	.196	78	.845	.67	3.46
	Equal variances not assumed	.198	75.73	.844	.67	3.42
Post-Test	Equal variances assumed	2.299	78	.024	8.14	3.54
	Equal variances not assumed	2.229	62.86	.029	8.14	3.65

As shown in table 2, the experimental group and the control group got a pre-test score mean of 61.74 and 61.07 respectively. The distribution of scores around the mean score in the pre-test is slightly higher in the control group ($SD = 15.87$ and $SE = 2.37$) compared to the experimental group ($SD = 14.61$ and $SE = 2.47$). Table 13 also shows that the experimental group and the control group obtained a post-test score mean of 72.51 and 64.38 respectively. In addition, the distribution of scores around the mean score in the post-test is quite higher in the experimental group ($SD = 17.80$ and $SE = 3.01$) compared to the control group ($SD = 13.87$ and $SE = 2.07$).

Using the independent samples t-test, to compare the pre-test score mean, sig. is 0.84 which is higher than 0.05. This shows that there is no significant difference between the pre-test scores mean for the control group and the experimental group. This means that the control group and the experimental group were equivalent at the start of learning bivariate statistics. To compare the post-test score mean, the independent samples t-test was used. Table 2 shows that the sig. is 0.024 which is less than 0.05. This shows that there is a significant difference between the mathematics assessment post-test scores mean for the experimental group and the control group. This means that there is higher learning achieved by the experimental group than by the control group.

4.1 The difference in the post-test mean scores of the control group and the experimental group

This study aimed to determine the effects of using Physics Education Technology simulations on students' achievement in bivariate statistics. To do this, the mathematics assessment post-test mean scores of the control group and the experimental group were compared using a t-test for independent samples. Table 3 shows the results.

Table 3: Difference in the post-test mean scores of the control group and the experimental group

Group Statistics

	Groups	N	Mean	Std. Deviation	Std. Error Mean
Post-Test	Experimental Group	35	72.51	17.80	3.01
	Control Group	45	64.38	13.87	2.07

Independent Samples Test

		t-test for Equality of Means				
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Post-Test	Equal variances assumed	2.299	78	.024	8.14	3.54
	Equal variances not assumed	2.229	62.86	.029	8.14	3.65

The result from Table 3 shows that the post-test mean score in the control group ($M = 64.38$) is quite less than that of the experimental group ($M = 72.51$) with a difference of 8.13. The distribution of scores around the mean score is quite higher in the experimental group ($SD = 17.80$ and $SE = 3.01$) compared to the control group ($SD = 13.87$ and $SE = 2.07$).
Using the t-test for independent samples, sig. is 0.024 which is less than 0.05. This shows that there is a significant difference between the mathematics assessment post-test scores mean for the experimental group and the control group.

This means that, in terms of gained knowledge in bivariate statistics, there is greater learning achieved by the experimental group which was exposed to PhET simulations than the control group which is exposed to the conventional teaching method.

Thus, the PhET simulations are more effective than the conventional teaching method in teaching bivariate statistics. This result led to the rejection of the null hypothesis that there is no statistically significant difference between the achievement of students exposed to PhET simulations and conventional instruction regarding pre- and post-tests scores.

The effectiveness of PhET simulations is supported by the study of Garcia (2020). He showed that the performance of the students exposed to the PhET simulations performed better as compared to the conventional teaching group. Jimoyiannis and Komis (2001) have seen in their study that students working with simulation exhibited significantly higher scores in research tasks than those who have not. According to McKinney (1997), simulation is one of the best educational teaching techniques as it addresses the senses of sight and hearing because it provides different stimuli in their presentation that are needed elements for effective education to happen.

5. Conclusion and Recommendations

5.1 Conclusion

The results of the comparison of the mathematics assessment pre-test mean scores of the control group who is exposed to the conventional teaching method and the experimental group who used the PhET Simulations method showed that the students in the control group had similar knowledge in bivariate statistics as that of the experimental group at the start of the study.
The results of the comparison of the mathematics assessment pre-and post-test mean scores of the experimental group who used the PhET simulation method showed that with the use of the PhET simulations, there is a significant achievement in the learning of the students in bivariate statistics as shown by the high increase from the mathematics assessment pre-test scores to the mathematics assessment post-test scores. The study concluded that PhET simulations can enhance students' achievement as the results of the comparison of the mathematics assessment post-test scores of the control group and the experimental group shown. This supports the study conducted by Davis (2007) which showed that there is an increase in the academic performance of the students after their exposure to interactive simulations. The study by Garcia (2020) also showed that the performance of the students exposed to the PhET simulations performed better as compared to the conventional teaching group.

5.2 Recommendation

The following recommendations are made in consideration of the results and conclusions of the study. Based on the results, the conventional teaching method and PhET simulations are useful teaching methods in teaching bivariate statistics. However, students who were taught by the conventional teaching method supported by PhET simulations performed better than those who were exposed to the conventional teaching method only in bivariate statistics. Thus, the researcher recommends that teachers incorporate PhET simulations into their classrooms to maintain quality education for the students and help them build a relational understanding of bivariate statistics.

Moreover, it was found that PhET simulations enhance students' achievement as the results of the comparison of the mathematics assessment post-test scores of the control group and the experimental group shown. Hence, the researcher recommends that the ministry of education through the Rwanda Education Board (REB) provides adequate ICT facilities to implement the use of PhET simulations in teaching bivariate statistics to support conventional teaching method. In addition, most mathematics teachers are not aware of the use of PhET simulations in teaching bivariate statistics. The researcher recommends that Rwanda Education Board (REB) should organize seminars on the use of PhET simulations in teaching mathematics and sciences.

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