The effect of computer simulation used as a teaching aid in students' understanding in learning the concepts of electric fields and electric forces

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Resumen

Este estudio investiga el uso de la simulación por computadora como medio de enseñanza en la comprensión de los estudiantes, en el aprendizaje de los conceptos de campos eléctricos y fuerzas eléctricas. Un centenar de estudiantes han participado en el estudio, los cuales fueron clasificados como grupo experimental (GE) y grupo control (GC) por un método de lotería. A los dos grupos se les enseñó el mismo tema durante una semana con el método de conferencia tradicional para el grupo de control; y al grupo experimental con la ayuda de simulaciones por ordenador. Además, un estudio piloto se llevó a cabo en la escuela Tana Haik, que es una escuela secundaria más grande, para probar la validez y confiabilidad del instrumento y medir el fondo de las muestras. Sus logros se midieron utilizando una prueba. Un pre-test fue dado antes del tratamiento para conocer el nivel de desempeño y el conocimiento previo. Y se administró un post test después del tratamiento para determinar si hubo progreso o no. Los resultados de los logros fueron analizados utilizando una prueba t. El análisis de los resultados indica que (por ejemplo), los estudiantes a los que se les enseñó el uso de simulaciones por computadora como medio de enseñanza, mostraron un mejor ritmo que el grupo control.

Palabras clave: simulación por ordenador, Grupo Experimental, Grupo Control, Logros, material didáctico, t-test.

Abstract

This study investigates the use of computer simulation as a teaching aid in students' understanding in learning the concepts of electric fields and electric forces. One hundred students were involved in the study that were classified as experimental group (EG) and control group (CG) by a lottery method. The two groups were taught the same topic for one week by the traditional lecture method for the control group and by the help of computer simulations for the experimental group. In addition, a pilot study was conducted at another school known as Tana Haik Senior Secondary School to test the validity and reliability of the instrument and to measure the background of the samples. Their achievements were measured using a test. A pre-test was given before treatment to know their performance level and pre-knowledge and a post test was administered after treatment to examine whether they showed a progress or not. Their achievement results were analyzed by using a t-test. The analysis of the result indicates that, students (EG) who were taught using computer simulations as a teaching aid showed a good progress than the control group.

Keywords: Computer simulation, Experimental Group, Control Group, Achievements, Teaching aid, t-test.

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I. INTRODUCCIÓN

The purpose of teaching at any level is to bring fundamental changes in the learner. Such changes may be in the form of acquiring intellectual skills, solving problems and inculcation of desirable attitudes and values. Teachers adopt different approaches to help students to acquire knowledge, skills and experiences [1]. Classroom use of Information and Communication Technology (ICT) for teaching science and technology has increased dramatically in recent years and has proven to be a very effective tool in variety of situations [2].

One of the challenges the society is facing in the modern world is the growing discrepancy, which exists between the rising demand of highly qualified manpower in the fields of science and technology and the low number of talented graduates in these fields. Since this is the concern of the people in the society, governments and professionals have to make unreserved efforts to change the situation. Now, almost everyone has realized that, in order students to have interest in science fields, it is necessary to consider more carefully the problems at all levels of the educational pyramid. The way children are trained to understand science and the environment they grew up may have an impact on their future options and affinities.

Many professionals are dedicated in teaching activities and in some cases, they have a special focus on the improvement of technology teaching in high schools by using different teaching methods like the computer simulated programs called Virtual Simulations (VS). Advances in computer technology have led to various high-quality educational tools including interactive programs, multimedia presentations and more recently virtual simulations. Virtual simulation is a computer interface characterized by a high degree of immersion and interaction making the user believe that he/she is actually inside the artificial environment.

Virtual Simulation is a highly interactive computer based multimedia environment in which the user becomes active participant in the computer world. A Virtual Physics simulation is an educational tool using a virtual reality interface that brings together a 3D model of real object and a virtual visualization of situations in an interactive manner [3]. A key future of VS is a real-time interactive where the computer is able to detect user inputs and instantaneously modify the virtual world in accordance with user interactions.

Virtual simulation environments often consist of technological hardware including computers, head-mounted displays, etc. Virtual technology may offer strong benefits in science education not only by facilitating constructive learning activities but also by supporting different types of learners like those who are visually oriented. Teaching physical concepts using VS enhances students' understanding by providing a degree of reality unattainable in traditional method of teaching. Within the high school educational community, multimedia is very necessary for a better success in educational aspects. Multimedia-based systems can provide the students with very rich sources of educational materials in a form that makes learning exciting.

VS has a wide range of applications in many disciplines and has reached a level of maturity for it to be applied to education. So, the recent technological developments in computer based simulations are now making feasible to look for VS as an important teaching aid [3].

Students who are mostly visual-spatial learners i.e. those who prefer to understand the world through their eyes and to express their ideas through graphical arts may dislike traditional method of teaching of Physics or other subjects because of its overemphasis on lecturing, rote memorization and drill and practice exercises. It is clear that, these and other students should be involved in their learning more than simply listening to lectures or reading textbooks. With the rapid advancement in three dimensional (3D) and computer technologies, VS has become much more user-friendly and affordable in prices and so within a few years, it will likely be incorporated as part of the IT in educational movement as advocated by many national or local governments in their educational reform agenda. Furthermore, it is quite feasible to develop various kinds of teaching and learning resources in science using certain kinds of lightweight (relatively simple and inexpensive) VS and 3D visualization technologies.

Based on our professional experience in teaching various science topics, we have uncovered and identified many topics, which are well-known to cause obstacles/difficulties to the students particularly in Physics subject. To minimize the difficulty, students can be taught and learn more effectively with the aid of 3D visualization and /or virtual simulations [4]. It is widely believed that [5], using VS as a teaching aid enhances student-centered (or self-organized) learning because of various unique features and educational values as embedded in 3D and VS media for learning.

Furthermore, those self-learning resources can help students develop their ability to visualize, understand and mentally construct the details of complex scientific data and models which will otherwise be lost, distorted or easily misinterpreted in planar 2D projection or monoscopic images. The development of information technology has played a great role in supporting many educational fields in a way that the user must be supported in a computer-assisted method of teaching. Using VS as a teaching aid in science fields enables students to acquire all the benefits mentioned above, that is, to develop an interest, make them to interact and exchange ideas with their friends, and achieve more in their examination results. Virtual simulation can also be used circumvent the physical, safety and cost constraints that limit schools in the types of environments they can provide for learning by doing [6]. The effect of replacing traditional teaching methods by using computer-based simulations have been published [6] and shown that, the students who learn Physics instruction using simulated programs perform conceptual mastery than their counter parts who were trained by the traditional method of teaching.

According to the report presented [7], when a traditional teacher-centered method is used in teaching Physics at high school level, students expect everything from the teacher where he/she is the source of every concept and they are a mere receivers of knowledge. After the lesson is covered by one-way teaching method, that is, from the teacher to the students, students are fighting to solve problems and miscellaneous exercises, which are found at the end of each chapter in the textbook without understanding the concepts of the lessons.

Laws [8] reported that, activity based environments combined with interactive discussions are superior to that of the traditional method of teaching to enhance conceptual understandings, experimental techniques and scientific literacy. Several authors [9] refer the use of simulations as a powerful means to smooth the approach to scientific concepts. From simple schemes to the color pictures that illustrate modern textbooks, there are several forms to transmit scientific content in a visual way. With adequate images, students may visualize some abstract concepts, allowing for a more direct contact with the subject being studied [10].

Understanding the behavior of electric fields and electric forces is a very challenging task by the students than applying any related formula to solve problems concerning electric fields and electric forces. In most cases,

electricity needs a physical mechanism for explaining the results of equations relating to the real situations. Dupin and Jashua [11] showed, the challenge is: that students aren't informed how these results are related conceptually to a model that tells what is happening in that situation. Lakin-Hein and Zollman [12] showed that, traditional instructions supported by technology improve achievement of students. Computers help the teacher to prepare animation and to show a model of abstract concepts. Donelly [13] explained that, complicated concepts can be presented and understood easily, with the help of simulations. Johnston [14] and Beerman [9] also showed that, different traditional methods of presentations that are supported by computer demonstration give a chance to the teacher to manage the way of presenting information. Beerman [9] showed that, information can be presented in a purposeful and targeted manner in computer demonstration. Cordes [15] concluded that, computers used in the class highly motivate students by fostering their interest and participation.

Nowadays, computers play a vital role in providing various forms of instructions. Up to now, the use of simulations in Physics education stood mainly on the creation of 2D representations. However, recent technological advances have created new possibilities and the visualization of 3D objects and data became increasingly important in learning several scientific subjects. Interactive digital video makes students be able to capture the process and the natural phenomena very easily [16]. Simulations can provide visualization of a process that cannot be easily understood in the classroom instruction [17]. According to Edward Redish [18], students' learning of electric fields by the help of simulations make easy to understand the abstract concepts.

In this study, the researcher investigated that, simulations enable students to learn Physics in general, and electric fields and electric forces in particular easily and in understandable manner at high school levels. The researcher measured the achievements of students after using the computer simulations as a teaching aid in the learning of the concepts of electric fields and electric forces.

II. METHODOLOGY

II.A Population settings

This study used all grade 10 students at Bahir Dar Academy Senior Secondary School found in Bahir Dar city, Ethiopia, as a target population. The sample for this study contains 100 students of all grade 10 students of the School. The sample was divided into two groups randomly. Each group contained 50 students. The researcher divided the two groups as an experimental group (EG) and control group (CG) by using a lottery system. Before the students engaged in the study, they were asked to provide a clear demographic information about themselves using a questionnaire.

II.B Class treatments

First, I treated the topic electric fields and electric forces for the CG for three periods of each 50 minutes by using the traditional lecture method in the class by the normal time schedule. The EG also took the same topic for three periods by using a simulation student centered method after the CG was treated. A manual was prepared to the EG students how to use the simulation on their computer settings. An interactive planned lecture was also used in this group.

II.C Experimental design

For each group pre-test and post-test with 18 questions were administered to compare students' understanding on the concepts of electric fields and the associated electric forces.

A t-test was applied to calculate the students' pre-test and post-test results of each group for the mastery of the concepts of electric fields and the associated electric forces.

II.D Investigation of background variables

In this study, investigation of the background variables was taken by administering a questionnaire with eight items. The items were Age, Sex, First Semester Physics results, Study Time, Feeling of Preparation, Expected Physics Score in Second Semester, Computer Literacy Level and Work Experience in Electronics and Electricity. Further more, to measure the equivalency of the two groups on their pre-test results, the researcher administered a Difficulty Index of Effects of Electric Force and Electric Field Concept Test (DIEFEFCT), on electric fields and the associated forces. This last has with 18 items and a t-test was applied to check whether the two groups were significantly different or not on their pre-test results.

II.E Age

Age may be one of the factors that determines the interest and attitudes of the learner to capture the desired concepts of the given content. A student who is older than the other in the same or another group is likely to score higher marks in examinations and may have better understanding of abstract concepts in Physics [19].

A χ^2- test was used to determine the significant difference between the groups age distribution.

TABLE I. Application of chi-square (χ^2) for age distribution of sample groups.

Age	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
≤ 14	0	2	0	2
15-17	50	43	49	45
18-20	0	3	1	1
≥ 21	0	2	0	2

The researcher considered the 2nd and the 3rd categories for this study and ignored the 1st and the 4th categories $\chi^2(2)$= 0.41 with p≥ 0.05 level which is less than the tabulated value 5.99. The result of the χ^2 -test indicates that the two groups were not significantly different in their age distribution.

II.F Sex

A research reported by Yalew Endawoke [20] showed that, women are under achievers in Physics. Therefore, the sex distribution of the two groups was an important step in this study to check the equivalency of the two groups. However, in this study, the researcher measures only the sex distribution not the achievement difference between sexes.

TABLE II. Application of χ^2 for sex distribution of the sample groups.

Sex	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
Female	32	31	30	29.75
Male	18	19	20	22.25

As indicated in table II, $\chi^2(2) = 3.9$ is less than the tabulated value of $\chi^2(2) = 5.99$. The distribution of male and female students in each group, the result of the χ^2 –test shows that there is no significant difference between the two groups in sex distribution.

II.G First semester Physics score

The first semester Physics score out of 100% was the measure of students' pervious achievements. The achievements of students in Physics may determine their next achievements in the subject.

TABLE III. First Semester Physics Score distribution of sample groups out of 100%.

Score	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
≤ 50	9	11	7	5
51-60	14	13	13	14
61-70	17	14	19	18
71-80	6	10	6	9
≥81	4	2	5	4

As can be seen from Table III, the distribution shows that, almost no significant difference exists in the score between the two groups ($\chi^2(4) = 1.96$ of p =0.05 which is less than the tabulated value of $\chi^2(4) = 9.49$).

II.H Study time

The amount of time taken by the students to study can be one of the factors in their achievements. It is expected that, a student who spends more time in studying Physics can score a high score as compared to those who spend very less time in studying Physics.

TABLE IV. Application of χ^2 for study time distribution per week of sample group.

Hours studied	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
0-4	33	28	34	30
5-7	17	20	16	18
8-10	0	2	0	2

The result ($\chi^2(3) = 2.06$ of p=0.05 level as compared to the tabulated value of $\chi^2(3)=7.81$) shows that, for each group the amount of time spent to study Physics is almost the same.

II.I Expected Physics score in second semester

Psychologically, if a student expects a high score, he/she can have confidence and a dream and works more to achieve the score. Thus, expectation of a high score might cause a change in students' achievement.

TABLE V. Application of χ^2 for score expectation distribution of sample group.

Expe-cted Score	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
≤ 50	0	2	0	2
51-60	0	5	0	5
61-70	12	10	14	11
71-80	30	35	26	30
≥81	8	8	10	2

Table V shows the expected Physics score by the students in each group in the second semester of the year 2009 and has no significant difference (χ^2 (4) = 3.12 which is less than the tabulated value $\chi^2(4)=9.48$).

II.J Feeling of preparation

Obviously, it is known that, the difference in the feeling of preparation would result a difference in the level of achievement. The feeling of preparation of the students in both groups is listed below.

TABLE VI. Feeling of preparation for Physics by the students.

Feeling of preparation	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
Strongly agree	14	10	12	10
Agree	36	20	38	20
Disagree	0	10	0	10
Strongly Disagree	0	10	0	10

Table VI, shows that, no significant difference between the two groups in terms of feeling of preparation (χ^2 (3) = 3.79 less than the tabulated value of χ^2 (3) = 7.81).

II.K Computer literacy level

The researcher used the computer laboratory room in Bahir Dar Academy Secondary School to carry out the study successfully. May be, prior computer literacy is one factor that affects students' achievement.

TABLE VII. Computer Literacy Level of Students.

Computer Literacy Level	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
Uncomfortable with computers	0	3	0	3
Marginally uncomfortable	0	2	0	4
Fairly comfortable	37	30	38	30
Very comfortable	13	15	12	13

As can be seen from Table VII, the result of the χ^2 test shows that, there is no significant difference between the two groups in terms of computer literacy level. (χ^2 (3) = 3.79 which is less than the tabulated value χ^2 (3) = 7.81).

II.L Work experiences in electronics and electricity

Prior work experience in electronics and electricity may affect the students' achievement and it has to be assessed using the background variable questionnaire.

TABLE VIII. Students' work experiences distribution.

Work experience	Experimental Group		Control Group	
	Observed	Expected	Observed	Expected
Yes	0	10	0	15
No	50	40	50	35

The response of the respondents (χ^2 (1) =2.31 and tabulated value is χ^2 (1) = 3.84) indicate that, there is no significant difference in their work experiences by the two groups.

II.M Pre-test score on DIEFEFCT conceptual test

In addition to using the background questionnaire to assess the demographic characteristics of the students in each group, we have also administered a pre-test to assess their background knowledge about the concepts of electric fields and the associated electric forces by using conceptual questions.

TABLE IX. Pre-test mean score of the EG and CG.

Group	Number (N)	Mean score	Standard deviation (Std)
CG	50	8.68	2.04
EG	50	8.66	2.08

As can be seen from Table IX, the average distribution of the pre-test result by the students in each group is almost the same and the difference can be taken as zero. This indicates that, their prior understanding was almost the same. So, what makes the difference is the post test administered after three periods treatments. One unpaired tailed t-test was applied to measure the performance of the two groups.

TABLE X. Result of unpaired t-test between the EG and CG in their pre-test results.

Quantity type	EG vs CG
t-test tabulated	2.02
t-test calculated	0.108
p-value	0.05
df	98
Mean Difference	0.02
Significance Consideration	Not significant

The result of the t-test analysis of the pre-test administered for both groups on DIEFEFCT to measure their prior understanding of electric fields and the associated electric forces shows that, there is no significant difference between the two groups in their results.

II.N Achievement of post-test

The result of the post-test which was administered after the end of the treatments for both CG and EG shows that, the EG students scored higher than the CG students.

TABLE XI. Post test mean score of the DIEFEFCT.

Group	N	Mean	Std
CG	50	10.22	2.7
EG	50	13.20	2.21

TABLE XII. One- tailed-t-test for CG vs EG post-test results.

Quantity type	CG vs EG
t-test tabulated	2.02
t-test	4.96
p-value	0.05
df	98
Mean difference	2.98
Significant consideration	Very Significant

The result in table XII shows that, there was a statistically significant difference in the post test scores of the CG and EG at the 5% level of significance ($p < 0.05$).

II.O Gain

The normalized gain factor from the post-test to that of the pre-test was computed using the formula:

$$g = \frac{post\,test\,\% - pre\,test\,\%}{100\% - pre\ test\,\%} \qquad (1)$$

where post test % is the students' score after the post test out of 100% and pre test % is the students score after the pre test out of 100%.

TABLE XIII. Mean gain of pre-test and post test of the CG and EG.

Group	Number (N)	Mean pre-test (%)	Mean post-test (%)	Mean difference (%)	Gain (g)
Control	50	43.4	53.8	10.4	0.18
Experi-mental	50	43.3	69.5	26.2	0.46

The gain (Hake, 1998) [21] divided the average gain values into high gain scores ($g \geq 0.7$) medium gain scores $0.3 \leq g < 0.7$ and low gain ($g < 0.3$).

As can be seen from table XIII, the result shows that, the EG who used the simulations as a teaching and learning aid to learn the concepts of electric fields and the associated electric forces had medium gain scores, while the CG who was treated the same topic by a teacher centered method had scored low gain score ranges.

II.P Comparison with the Pre-test Performance

One-tailed t-test was applied to the two groups to determine if the difference in the mean scores were statistically significant or not.

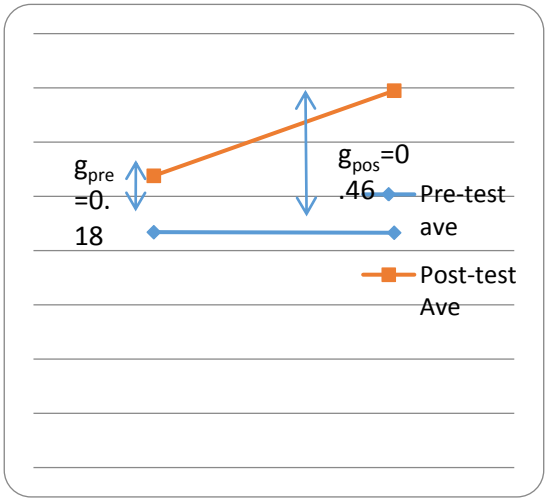

FIGURE 1. Mean gain of pre-test and post test of the CG and EG after and before treatment.

TABLE XIV. Result of t-test between CG and EG in their pre and post test scores.

Item	CG			EG		
	CG_{Pre}	CG_{post}	CG_{pre} vs CG_{post}	EG_{pre}	EG_{post}	EG_{pre} vs EG_{post}
t-test	0.054	2.48	3.21	0.054	4.28	10.08
p-value	0.05	0.05	0.05	0.05	0.05	0.0014
df	49	49	49	49	49	49
Mean difference	43.4	53.8	1.54	43.3	69.5	4.54
Significance consideration			Signifi-cant			Very signify-cant

Quantity type	CG_{pre} vs CG_{post}	EG_{pre} vs EG_{post}
t-test	3.21	10.08
p-value	0.002	0.0014
df	49	49
Mean difference	1.54	4.54
Significance consideration	significant	Extremely significant

The result in Table XIV shows that, there was a significant amount of progress observed on both groups but the mean difference between the pre-test and the post-test result was highest for the EG and lowest for the CG.

III. DISCUSSION

The result of this study suggests that, computer simulations used as a teaching aid in learning the concepts of electric fields and electric forces help students to master the abstract concepts very easily. The experimental group (EG) who used computer simulations as a teaching aid in an interactive manner with the user interface in the topic fields and electric forces master the abstract concepts better than, those of the control group (CG) who did not use computer simulations at all. So, the findings of this study are consistent with other previous findings [22].

The result analysis of the electric field, electric force, the mixed items, the electric field lines and strength, the mixed items and the schematic items administered in post test showed that students who used computer simulations technique as a teaching aid in learning the concepts of electric fields and the associated electric forces achieved more than the control group. This indicates that, students who were supported by computer simulations in learning the electric fields and the electric forces had a better understanding of the concepts of electric fields and electric forces.

The comparison of the post test result with their pre test result showed that, the EG achieved more than the CG. That is, the mean score of the EG in post test result is better than their pre test mean score. The mean difference is very significant for the EG. But, even if there was a mean difference in the score of a post test result with the pre test result by the CG, the mean difference was not yet significant.

This indicates that, the EG understands the concepts of electric fields and the associated electric forces better than those of the CG. Thus, computer simulation aided teaching and learning of electric fields and the associated electric forces had enabled students to understanding better the abstract concepts of electric fields and the electric forces.

IV. CONCLUSION

After conducting the pre test and the post test, the result of students was analysed by applying a t-test for each type of question for both groups. The result of the t-test, conducted on the pre-test for the CG and EG, shows that, there was no significant difference observed. This indicates that, the two groups were found on the same level of understanding on the concepts of electric fields and the electric forces.

Out of eight questions, the mean score of the two groups from their pre test result was 1.01 and 1.04. This suggests that, both groups of students do not yet understand the concept of electric fields clearly. Thus, these topics need a mechanism, especially using a best teaching aid to help the students in creating their own mental model for a better understanding.

After the post test was conducted, the experimental group (EG) who used computer simulations as a teaching aid in learning the concepts of electric fields showed a great progress. After the post test was conducted, the mean score was found out to be 3.24 and 6.17 for CG and EG respectively. This is because computer simulations in learning the electric fields would provide the students (EG) to look in how the electric fields emanate from the positive test charge and enter the negative charge placed in the vicinity region around the positive test charge.

The simulation helps the students to place another charge in that region and see the effects visually. The simulation also provides them to see where the electric field lines were close to each other and dispersed each other on the interface.

All these phenomenon of a static charge were visual.

Thus, students who used the computer simulations in learning the concepts of electric fields visualize the properties by the user interface. This provides the students to create their own mental models about the electric fields in general, understand and master the concepts of electric fields very easily in particular. The achievement of the EG on the mastery of the concepts of electric fields was measured by the post test result and the result was analysed by applying a t-test. The result of the t-test was 3.19, which was less than the t- value of significance difference 5% [20]. This indicates that, the experimental group was better in understanding the concepts of electric fields than the control group.

The result of the t-test of the post test administered to measure their understandings of the concepts of electric forces indicated that, there was a significant difference ($p<0.05$) between the two groups. The result of the t-test showed that, the EG scored better than those of the CG.

The computer simulation programs help the students to understand:

Where the electric force that is acting on a point, charge placed in the region is strong or weak; and even the user interface makes them to insert their own input; and displays whether the force is attractive or repulsive; and maximum or minimum, by increasing and decreasing the separation between the charges.

This indicates that, computer simulations used as a teaching aid in learning the concepts of electric fields and electric forces help the students to understand the concepts very easily. From the result of the t-test, there was a significant difference in the achievement of their scores on the post test by answering questions asked about the electric field, force and strength.

The result indicated that, the EG was better than that of the CG. Therefore, the EG who used computer simulations as an aid in learning the concepts of electric field, force and strength were understood better than those of the CG. Thus, computer simulations help the students to combine the concepts of electric fields and the associated electric forces together and understand the concepts by integrating each other very easily.

The t-test result showed that the experimental group was better in scoring in the post test than those of the control group. The EG used computer simulations were capable enough in interpreting figures related to those of electric fields and electric forces. Because, during the treatment, these students were made to understand each aspect of the property of electric fields and electric forces visually and they already create their own mental models about the electric fields and the electric forces.

Generally, the academic achievement of the EG that was measured by the post test examination was better than those of the CG.

Therefore, the result of this study indicates that, the students who used the virtual simulations in learning the concepts of electric fields and the electric forces were more satisfied with their instruction and even they understood the topic and they found the teaching material in learning electric fields and electric forces more engaging. From the result, we can infer that, the VS is a very useful as teaching aid especially in the case of highly interactive visualization of abstract concepts such as the electric fields and electric forces.

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