Can computer simulations substitute real laboratory apparatus?

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QVO NON ASCENDAM?

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Abstract

This study investigates the effectiveness of computer simulations in teacher centered (STC) and student-centered (SSC) approaches in replacing real equipment laboratory (REL) in grade 12 physics course. The direct current (DC) circuit experiment was adopted to compare simulations in both cases with the real equipment. Particular attention was given to students' conceptual understanding and skills of manipulating real equipment. Sixty four students were divided into three instructional groups. The students in computer simulation teacher-centered (STC) group observed and participated when the experiment was done; students in computer simulation student centered (SSC) group performed computer simulation by themselves; and real equipment laboratory (REL) group used traditional way to perform the experiment by themselves. Students' understandings of DC circuit concepts were assessed using Determining and Interpreting Resistive Electric circuit Concepts Test (DIRECT). Other assessment measures included the time taken by a laboratory group of three students to construct a circuit of series-parallel combination. T-test statistics revealed statistically significant difference between instructional treatment and students' understanding of DC circuits as measured by DIRECT. The results of this study show that the use of simulation in either setting can serve to enhance students' achievement. Results of the statistical analysis for voltage and schematic diagram questions also showed no significant difference between treatment and understanding of these concepts, while a significant difference between concepts such as current and resistance and the instruction methods was observed. The resulting mean time taken on building the given circuit was 15.171 minutes for REL, 15.029 for STC and 13.457 for SSC. Both SSC and STC groups get the skill of using real equipments though they did not use real instruments.

Keywords: Simulation, Direct current circuit experiment, Real laboratory.

Resumen

Este estudio investiga la eficacia de las simulaciones computacionales en un enfoque centradas en el profesor (STC) y centradas en el estudiante (CSE) en sustitución de equipos de laboratorio real (REL) en el curso de física de grado 12. Se adoptó el experimento de circuitos de corriente directa (DC) para comparar las simulaciones en ambos casos con el equipo real. Se prestó especial atención a la comprensión conceptual y las habilidades de manipulación de equipos reales de los estudiantes. Sesenta y cuatro alumnos se dividieron en tres grupos de enseñanza. El grupo de estudiantes de simulación centrada en el maestro (STC), observó y participó cuando se hizo el experimento, los estudiantes de simulación centrada en el alumno (SSC), realizaron simulación computacional por sí mismos, y el grupo del equipo de laboratorio real (REL) utilizó la forma tradicional de realizar el experimento por sí mismos. La comprensión de los estudiantes de conceptos de circuitos de CC se evaluó utilizando la prueba de Determinación e Interpretación de Conceptos de Circuitos Eléctricos Resistivos (DIRECT). Otras medidas de evaluación incluyeron el tiempo utilizado por un grupo de laboratorio de tres estudiantes para construir un circuito de combinación serie-paralelo. La estadística de prueba T reveló diferencias estadísticamente significativas entre el tratamiento de instrucción y comprensión de los estudiantes de los circuitos de corriente continua, medida por DIRECT. Los resultados de este estudio muestran que el uso de la simulación en cualquier entorno puede servir para mejorar el rendimiento de los estudiantes. Los resultados del análisis estadístico para voltaje y preguntas de diagrama esquemático tampoco mostraron diferencias significativas entre el tratamiento y comprensión de estos conceptos, mientras que se observó una diferencia significativa entre conceptos como corriente y resistencia y los métodos de instrucción. El tiempo promedio para la construcción del circuito dado fue de 15.171 minutos para REL, 15.029 para el STC y 13.457 para el SSC. Tanto los grupos SSC y STC obtuvieron la habilidad de utilizar equipos reales, aunque no hicieron uso de instrumentos reales.

Palabras clave: Simulación, Experimentos de circuitos de corriente directa, Laboratorio real.

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I. INTRODUCTION

In the past few decades, significant amount of effort have gone to improve physics instruction through active participation of students in their learning. Having the belief that learning of concepts in physics can be improved in an activity, rather than sitting and listening new information, laboratory activity that support active engagement of students and promote conceptual understanding is indispensable.

Research findings suggest that traditional lecture instruction is ineffective in dealing with students' misconceptions. Traditional lecture instruction did not consider the view of students. So it cannot transform the concepts as well as can not improve the shortcoming of students [1]. The alternative helpful teaching approaches should emphasize the development of these situations that would assist active engagement of students in learning and mastering physics.

Among the many learning theories, constructivism advocates the involvement of students in their learning. The main idea of the employment of the constructivist's approach to learning can be achieved using the effects of laboratory tools that make easy students active participation in physics teaching and learning.

Few studies attempted to examine thoroughly the laboratory instruction in the development of conceptual understanding and participation of students. Koponen [2] concluded that the knowledge of physics students in the subject showed much progress in their understanding and application of it in new situations.

On the virtue that the same kind of change can be achieved in different ways for conceptual understanding or capacity of using equipments [3, 4]. It is interesting that the education gain through laboratory exercise can be achieved through simulations.

Finkelstein, *et al.* [5] evaluated the potential of simulations in introductory physics at a university to completely substitute real laboratory activities. Finkelstein and et al reported that students who used computer simulations instead of real laboratory equipments performed better on conceptual questions related to DC circuits in the final exam, and showed a much better capacity in handling real lab equipments. But they do not suggest simulation in promoting conceptual learning and comfort ability with real equipments. It sounds necessary, however, to deeply examine Finkelstein, et al's conclusion; particularly in case of doing real laboratory is impossible due to financial problems and danger of the experiments, considering the rationale that makes them to conclude so. The studies made so far seem to bind conceptual understanding with laboratory activities.

On top of this, delivering physics instructions without active engagement of students has little to do in developing their conceptual understanding. Indeed, innovation of computer gives a new dimension to be exploited in the laboratory. Hence what have to come contingent with the idea of replacing real equipment laboratories by computer simulations are the pedagogical advantage and their cost and maintenance. Simulations are by far better than real equipped laboratories with these two regards [6]. Knowing that simulations can replace real equipment laboratories effectively, does not guarantee that we can use it. As buying and maintaining equipment of real laboratories is challenging to our capacity, fulfilling computers in high schools is also difficult task to our capacity.

However interactive lecture demonstrations of simulations have a beneficial effect on students' conceptual development. Sokoloff *et al.* [8] have used and assessed the efficiency of microcomputer based interactive lecture demonstrations for a long period of time. Interactive lecture demonstrations contained simple physics experiments. Prediction of the results in the experiment, small group discussions with their nearby friends, observation of the experiment when done virtually and comparison of observations and expectations are ways of engaging students in their learning. Students who participated in interactive lecture demonstrations showed significant improvement in learning and understanding of basic concepts as compared to those who were taught by traditional lectures.

Hence, making lecture instruction to be supported by laboratory exercise is an inalienable element in promoting conceptual understanding of students. Conceptual understanding of physical phenomena needs active involvement of students. And then actual learning and better understanding of concepts can be achieved. It is when laboratory activities are carried out that science students be able to understand natural phenomena. A drift from this could deter the aims of the physics education. But economical problems urge us to drift from the aims.

At this point, it is inescapable to investigate whether simulations in student-centered or teacher-centered methods are as effective as real equipments in enhancing conceptual understanding and mastery of manipulating real equipments in Ethiopian context.

The purpose of this study was, thus, to investigate the possibility of computer simulations in different teaching preferences to completely substitute real apparatus laboratories within a group of grade 12 natural science students as measured by DIRECT test instrument and timing data. With the specific objectives of determining whether incorporating new technology into the physics classroom have a profound effect on students understanding of DC circuit irrespective of the instructional method used and whether the skill of manipulating real equipment of labs after performing the DC experiment using only simulations is gained.

II. PURPOSE OF THE RESEARCH

Researches in physics education have made improvement in including computer simulations in the laboratory to improve the conceptual learning of students. Few efforts had been done to completely replace real equipments laboratories by means of simulations [9, 5].

This study focused on the potential of computer simulations in student-centered and teacher-centered instructional methods to completely substitute real equipment laboratories. An attempt has been done to assess the effectiveness of simulations in conceptual development of students as compared to real equipments in DC circuits.

This study investigated the problem and sought to find answers to the questions presented below:

1. Will there be a significant difference in achievement based on DIRECT test between students in the simulation groups with different instruction settings and those in the real laboratory group?
2. Will students learn the same concept in simulation with teacher-centered and student-centered basis and real experiment in DC circuits?
3. Will students develop an ability of using real equipments though they do the experiment via computers (for student-centered) group and they watch when the experiment is done on the computer (by the researcher for teacher-centered group)?

III. METHODS

A. The sample

The sample for this study included 64 students, with 60 male and 4 female students, out of a population of 288 grade 12 natural science students at Damot Higher Education Preparatory School in Finote Selam, Ethiopia. The sample was divided into three groups. The first two groups included 21 students each, while the third group included 22 students. The selection of the sample and their distribution in groups was done randomly. The first group was also randomly assigned as the Real Equipment Laboratory group (REL), the second to the Simulation Teacher-centered (STC) group while the third was assigned as the simulation Student-centered (SSC) group. Before the students engaged in the experiment, they were asked to provide demographic information about themselves using a questionnaire.

B. Treatments

For a period of one hour, each group took a lecture about DC circuits. This lecture was proposed to remind them the physical concepts and mathematical derivations of the DC circuits that they had already learnt. It also served to answer questions that were raised by the students. Laboratory activity in real equipments and computer simulation was designed for students to practically apply the DC circuit. Two manual for REL and SSC group were prepared and an interactive planned lecture was used to the STC group.

All three groups did laboratory according to their group's experimental environment for nearly two hours. The laboratory group did the DC circuit laboratory using real equipments like bulb, wire, battery, ammeter and voltmeter. The STC group watched and participated when the researcher performed the experiment using virtually created equipment of bulb, wire, battery, ammeter and voltmeter. The SSC group performed the experiment by themselves using virtual DC circuit equipments using a computer. Students in the REL and SSC group worked in groups of three and they self-selected their group members.

The software used in this study was Physics Educational Technology (PhET), which was developed by the physics education research (PER) group of the University of Colorado, in the United States of America. The PER group prepared about 50 simulations from mechanics to electricity and thermodynamics. All are freely available and could be downloaded online from the website [http://phet.colorado.edu]. The simulation used in this study was Circuit Construction Kit. These simulation models are highly interactive, allow students to take part and provide instant feedback to students. They are highly visual, for example they show the movement of electrons in the circuit. The physical principle that holds in real equipment experiments also holds here [5, 34].

Circuit Construction Kit gives an opportunity to study the behavior of DC circuits using virtual materials such as resistors, light bulbs, and batteries. Students can change resistance of the bulb or voltage of their battery source. Students can also use batteries and bulbs with or without internal resistance.

The simulation software PhET was installed only on computers in one of the IT rooms that did not have class hours. SSC group only used this room at their program. The DC circuit experiment was made available to students only during the scheduled time of the laboratory group in the physics laboratory of the school. Therefore, students did not do the experiment either in laboratory or in simulation out of the scheduled time.

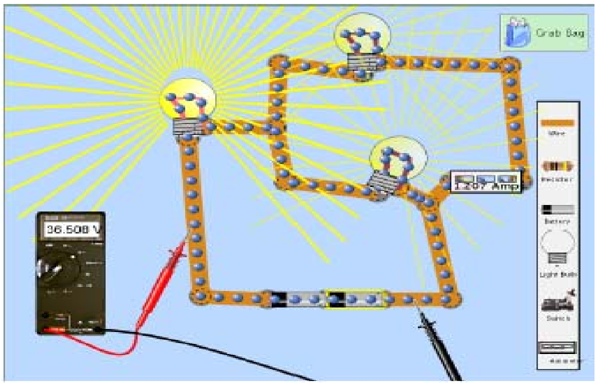

FIGURE 1. Screen shot of construction circuit kit.

C. Instruments

One of the instruments used in this study was Determining and Interpreting Resistive Electric circuit Concepts Test (DIRECT), which was developed by Paula V. Engelhardt and Robert J. Beichner at North Carolina State University [35]. The test was developed to evaluate students' conceptual understanding of DC circuits. The test consisted of 29 multiple-choice questions. Each item had five alternatives to choose from.

Though DIRECT is supposedly valid and reliable across countries, a pilot study was done at Damot Preparatory School to assess its reliability and validity in the Ethiopian context. DIRECT version 1.1 was used and it was administered to 24 grade 12 students from Damot Preparatory School. The test took approximately 40 minutes to complete. The statistical analysis of the test for this pilot study is shown in Table I.

TABLE I. Item difficulty, item discrimination and item reliability of the pilot test for each questions of DIRECT.

Question	Number of students who choose each alternative					Difficulty	Discrimination	Reliability
	A	B	C	D	E			
1	5	4	0	12	**3**	0.125	0.167	0.425
2	1	7	4	10	**2**	0.083	0.167	0.517
3	3	5	**13**	0	3	0.542	0.167	0.211
4	3	15	1	**4**	1	0.208	0.667	0.614
5	**7**	3	7	6	1	0.292	0.333	0.313
6	2	4	7	4	**7**	0.292	0.500	0.388
7	1	**15**	2	4	2	0.625	0.500	0.325
8	3	5	**14**	2	0	0.583	0.500	0.278
9	12	1	4	**5**	2	0.208	0.500	0.614
10	0	1	18	1	**4**	0.167	0.167	0.035
11	**3**	7	3	9	2	0.125	0.333	0.262
12	8	8	24	**3**	1	0.125	0.333	0.699
13	2	9	**10**	3	0	0.417	0.500	0.389
14	4	4	3	**9**	2	0.375	0.000	0.143
15	5	2	**9**	5	3	0.375	0.833	0.565
16	4	7	**7**	4	2	0.292	0.333	0.138
17	6	1	10	**7**	0	0.292	0.500	0.138
18	0	5	**10**	9	0	0.417	0.000	0.002
19	7	4	**12**	1	0	0.500	0.167	0.329
20	2	1	5	11	**5**	0.208	0.167	0.055
21	5	0	6	**11**	2	0.458	0.333	0.084
22	3	**10**	2	4	5	0.417	0.000	0.090
23	8	7	2	**0**	7	0.000	0.000	0.000
24	16	2	5	**1**	0	0.042	0.000	0.126
25	**1**	15	5	2	1	0.042	0.000	0.102
26	8	4	7	**4**	1	0.167	0.333	0.249
27	3	**6**	7	3	5	0.250	0.833	0.701
28	10	0	4	**6**	4	0.250	0.000	0.112
29	3	**8**	6	4	3	0.375	0.333	0.049

Note: The correct answer is in bold for each questions.

D. Statistical Evaluation of Pilot Testing For DIRECT

Taking the data from the pilot study, three statistical tests were conducted. These are item difficulty index, item discrimination index and test of reliability. The discussion of each test and the result found is briefly presented here under.

E. Difficulty Index

Difficulty index is a measure of difficulty of each test item. Usually a value between 0.3 and 0.9 show the accepted level of difficulty for an item [43]. Since it is difficult to control each item in this range, average difficulty index was calculated and found to be 0.3.

F. Discrimination Index

Discrimination index measures the extent to which a single test item differentiates students who scored well in the test from those who did not. We used top 25% as the high group and the bottom 25% as the low group and computed the discrimination. After calculating the discrimination power of all 29 items, we found that question number 11 has a negative discrimination index. This items was eliminated.

It is also found that question number 14, 18, 22, 23, 24, 25 and 28 had 0 discrimination powers, meaning they did not distinguish between high achievers and low achievers of the test. These questions were also discarded. Question number 1 and 2 had been discarded because they have low difficulty index, meaning they are very difficult, and hence unable to discriminate examinees based on their ability. In this pilot testing, it was found that the average discrimination index for DIRECT is 0.27. After avoiding the above items, the average discrimination index for DIRECT with 19 items was 0.41. Table II below shows the difficulty and discrimination index for DIRECT with 29 and 19 questions.

TABLE II. Summary of Statistical Results for the Pilot Test.

Test statistics	Possible value	Desired value	Observed value	
			For 29 items	For 19 items
Difficulty	[0,1]	≥ 0.3	0.30	0.33
Discrimination	[-1,1]	≥0.3	0.27	0.41
Reliability	[0,1]	≥0.7 or ≥0.8	0.64	0.795

G. Kuder-Richardson reliability index

Kuder-Richardson reliability index measure the consistency of the whole test. This method is widely adapted to situations where the test is administrated once. The range of Kuder-Richardson reliability index is between 0 and 1. For group measurement, the reliability index should be higher than 0.7 while for individual measurements it should be 0.8.

In the DIRECT analysis, we used KR-21 formula and found the reliability index to be 0.64, which is not adequate for group measurements. But for the 19 questions, it was 0.80 which is acceptable for both group and individual measurement purposes.

The validity of DIRECT was checked. Validity is the ability of the test to measure what it is intended to measure. Emphasis was placed on two aspects of validity: content and construct validity. Content validity was undertaken by giving the test and objectives of DC Circuit from grade 12 physics curriculum guides to three instructors at Bahir Dar University, two physics teacher at Bahir Dar Preparatory School and Damot Preparatory School and two physics graduate students at Bahir Dar University, for their careful scrutinize. They examined the test and matched each test items with the intended objectives. While all the selected evaluators filled and returned the critically examined test package on time, only one instructor at Bahir Dar University, two physics teacher at Bahir Dar Preparatory School and Damot Preparatory School and two graduate students. The test item was then matched to its respective objective by considering it mostly chosen by these experts. Table III shows the result.

TABLE III. Objective from Physics Curriculum guide of grade 12.

Objectives	Question number from DIRECT	
	For 29 items	For 19 items
Apply the concepts of voltage to different kind of circuits	6,7,15,16, 24,25,28,29	6,7,15,16,29
Understand and apply current to a variety of circuits	3,8,11,12,17, 20	3,8,12,17,20
Interprets diagrams of different circuits	4,13,22	4,13
Use the concept of resistance in circuits	5,14,21,23, 27	5,21,27
Distinguish and explain a circuit	2,9,10,12,18, 19,26	9,10,19,26

On the other hand, construct validity of DIRECT was assessed using interviews. The interview was used to find out whether the questions were being understood in a way that reflects the objective for which they were intended. The interview was conducted after the pilot study using 10 questions from DIRECT with 4 students who participated in the pilot study. Students were asked to identify the symbols used in the test and to provide some justification for their responses. All of the students understood the electrical symbols in the test. Only two students changed their answers for 3 questions from what they put in the test sheet of the pilot study.

The second instrument used in this study was timing data. After students finished their DC circuit experiment, they were asked to complete the series-parallel circuit shown in Figure 1 using real equipments. The timing data was the time the students took to finish the aforementioned circuit, though STC and SSC groups did it using computer simulations. For laboratory group and SSC group they did it within their assigned groups of three, while the STC group created a group of three by their own.

H. Experimental Design

For each group pre-test and post-test were administered to compare students' understanding of DC circuit with 19 questions only. T-test was calculated for students' pre-test and post-test scores. Also t-test were computed for students' post-test results of each group, for concepts incorporated in DC circuit experiment and for the time data.

Microsoft Excel and SPSS were employed to analyze the data, specifically to put data into spreadsheets, to calculate t-test and to make graphs.

I. Description of the Participant

As mentioned earlier, grade 12 natural science students of Damot Preparatory School were participant of this study. Out of 288 natural science students, 75 were randomly selected for the case study.

Since students were randomly assigned to three groups, negligible difference in a background factors was expected and later confirmed using students' background questionnaire. The questionnaire had nine various factors that could affect achievement of students in DC circuits. These items were presented and criticized by two high school teacher from Damot and Bahir Dar preparatory schools and one instructor from department of Pedagogical Science at Bahir Dar University.

The questionnaire contains items that probe the background information about students like age, computer experience and electronic experience was prepared. Each item was written with maximum effort to make the statements as clear and concise as possible. A pilot testing was done for this questionnaire at Bahir Dar preparatory school grade 12 natural science students. These students were also asked to give any comment at the end of each item. Some modifications were made to some items of the questionnaire after analyzing the responses of students who took part in the pilot test.

After incorporating all suggestions which were valuable, the questionnaire was given to the selected 75 students during the pretest time. 11 students were absent during instruction delivering and at the exam hall of the post test. The background survey was done for only 64 students who participated throughout the study and presented in Table IV.

TABLE IV. Background information of the participant.

		REL	STC	SSC
Age	<16	4	2	3
	17-18	7	8	6
	19-20	10	11	11
	>21	-	1	1
Gender	Male	19	21	20
	Female	2	1	1
1st semester Physics (Maths) [Expected] marks	< 50	1(-)[1]	3(-)[-]	3(-)[-]
	51-60	3(3)[3]	5(2)[3]	6(2)[3]
	61-70	6(7)[4]	5(6)[5]	5(5)[6]
	71-80	6(6)[10]	5(10)[9]	4(9)[9]
	>81	5(5)[3]	4(4)[5]	3(5)[3]
Study hour per week	0-4	4	-	6
	5-8	6	7	5
	9-12	7	10	6
	13-16	3	4	4
	17-20	1	1	-
Feeling of Preparation	Strongly Agree	4	5	4
	Agree	14	12	11
	Undecided	1	2	3
	Disagree	2	2	2
	Strongly Disagree	0	1	0
Computer literacy	Excellent	-	1	-
	Very good	3	3	4
	Good	16	17	15
	Fair	2	1	4
	Bad	0	0	0
Work in electronics	Yes	1	1	0
	No	20	21	21

The demographic data presented in Table IV show that there is no significant difference among each group in their socio demography, that verifies the apparent similarity of each group before the study.

E. Pretest scores on DIRECT conceptual test

In addition to background questionnaire used to assess the demographic characteristics of the treatment groups, the pre test scores of each treatment group on DIRECT conceptual test can be used as another source of information. The test was administered concurrently to the three groups after the lecture had been given to all three groups. These DIRECT test measures students understanding of DC circuits. The test is also convenient to high school students.

TABLE V. Pretest mean scores of DIRECT.

Group	N	Mean	SD
REL	21	6.67	3.04
STC	22	6.18	2.07
SSC	21	7	2.83

The SSC group scored higher on the pretest than the STC and REL groups. Also REL scored higher scores compared to STC group. As a result, unpaired two-tailed t-tests were subsequently performed on the three pairs of groups (REL vs. STC, REL vs. SSC and STC vs. SSC). The results are presented in Table VI.

TABLE VI. Results of unpaired t-tests between REL and STC, REL and SSC, and STC and SSC in their pre test result.

	REL vs. STC	REL vs. SSC	SSC vs. STC
t-test	0.554	0.368	0.969
p-value	0.583	0.715	0.338
Df	41	40	41
Mean difference	0.485	0.333	0.818
Significance	Not Significant	Not Significant	Not Significant

Though the results of the DIRECT pre test indicated that the students in SSC group scored higher scores than the STC and REL groups, the t-test demonstrated no significant difference between treatment groups in their understandings of DC circuits.

IV. FINDINGS AND COMMENTS

A. Post-test performance

The SSC group scored higher on the post test than the STC and REL groups. Also STC group scores were higher compared to REL group. Table III shows means and standard deviations of the post test.

TABLE VII. Post test mean scores of DIRECT.

Group	N	Mean	SD
REL	21	9.52	2.89
STC	22	11.18	2.44
SSC	21	12.57	3.38

Unpaired two-tailed t-tests were performed on the three pairs of groups (REL vs. STC, REL vs. SSC and STC vs. SSC) to determine if difference in mean scores were statistically significant. The results are presented in Table VIII.

TABLE VIII. Results of unpaired t-test between REL and STC, REL and SSC, and SSC and STC in their post test Result.

	REL vs. STC	REL vs. SSC	SSC vs. STC
t-test	2.035	3.137	1.549
p-value	0.048	0.003	0.129
Df	41	40	41
Mean difference	1.658	3.048	1.390
Significance	Significant	Very Significant	Not Significant

As clearly seen in Table VII, there is a statistically significant difference in the post test scores of REL group and STC group as well as between REL groups at 5% level of significance ($p > 0.05$). But no statistically significant difference was observed between STC and SSC groups.

The result suggested that a difference in achievement may have existed between SSC & REL and STC & REL. But no difference was observed between SSC & STC groups in their achievement.

Histograms of the pretest and post test scores for each treatment group are presented in Figure 2. The SSC group shows better progress in the mean score compared to STC and REL group, though STC and REL groups had progress in mean scores of the post test compared to their pretest.

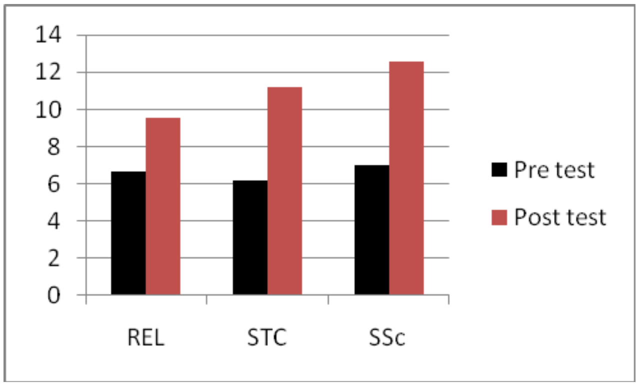

FIGURE 2. Students score after and before instruction.

B. The Hake Factor

Average normalized gain or the Hake Factor, h, was computed using the formula [38]:

$$h = (\text{post} - \text{pre})/(1 - \text{pre}).$$

The effectiveness of the instructional treatments for each of the three experimental groups was assessed using average normalized gains, which were calculated for each group. The average gains are given in Table IX, along with the average pretest and post test scores for each group.

TABLE IX. Summary of mean normalized gains for the three groups.

Group	N	Pretest	Posttest	H
REL	21	6.67	9.52	0.21
STC	22	6.18	11.18	0.39
SSC	21	7	12.57	0.48

Hake [38] divided the average gain values into high-gain scores ($h \leq 0.7$), medium-gain scores ($0.5 < h \leq 0.3$), and low-gain courses ($h < 0.3$). As depicted in Table 17 the average gains for the REL, STC, and SSC groups are 0.21, 0.39, and 0.48 respectively. Both simulations groups are in medium-gain score range while the REL group is in low-gain scores range.

C. Comparison with the pretest

A one-tailed t-test was performed on the three groups to determine if difference in mean gain scores were statistically significant. The results are presented in Table X.

TABLE X. Results of paired t-tests between REL, STC, and SSC pre and post test result.

	REL pre vs. REL post	STC pre vs. STC post	SSC pre vs. SSC post
t-test	4.650	9.651	9.611
p-value	0.0002	<0.0001	<0.0001
Df	20	21	20
Mean difference	2.857	5	5.571
Significance	Extremely Significant	Extremely Significant	Extremely Significant

Table X indicates that significant amounts of progress were made as a result of the different treatment methods. But the mean difference between pretest and post test was highest for SSC groups. The lowest was recorded for REL groups.

D. Post test analysis of subtopics

The post test questions were split into specific categories as electrical current questions only, voltage questions only, schematic diagrams questions only, resistance questions only and mixed questions. Results of the means and standard deviations for each category of post test items are shown below.

D.1 Electrical Current

Question number 3, 8, 12, 17 and 20 were the electrical current questions. They need the conceptual understanding of students of conservation of current to a variety of circuits to be answered. They need explanations of the microscopic aspects of current flow in the circuit using electrostatic terms such as potential difference.

TABLE XI. Post test mean scores of DIRECT for current questions only.

Group	N	Mean	SD
REL	21	2.62	1.16
STC	22	2.86	1.04
SSC	21	3.61	1.02

Based on the results in Table XII, no significant difference exists between REL & STC in mean scores of current questions from DIRECT. However, there exists a statically significant difference between REL & SSC and STC & SSC.

TABLE XII. Results of unpaired t-tests between REL and STC, REL and SSC, and STC and SSC in current questions only.

	REL vs. STC	REL vs. SSC	STC vs. SSC
t-test	0.729	2.704	2.150
p-value	0.47	0.01	0.038
Df	41	40	41
Mean difference	0.247	0.952	0.708
Significance	Not Significant	Significant	Significant

This suggested that students who did the simulation DC experiment by themselves outperformed those who used real equipment laboratories and who watched the simulations when performed by the researcher.

D. 2 Voltage

Questions included here were question number 6, 7, 15, 16 and 29. To answer these questions students must have internalized the concept of potential difference to series and parallel circuits.

TABLE XIII. Post test mean scores of DIRECT for voltage questions only.

Group	N	Mean	SD
REL	21	2.67	1.2
STC	22	2.86	0.94
SSC	21	3.14	1.39

The result shown in Table XIV reveals no statistical difference between different instructional methods. These results indicated that students from REL and SSC groups attained nearly equal means.

TABLE XIV. Results of unpaired t-tests between REL and STC, REL and SSC, and STC and SSC in current questions only.

	REL vs. STC	REL vs. SSC	STC vs. SSC
t-test	0.601	1.364	0.953
p-value	0.551	0.180	0.346
Df	41	40	41
Mean difference	0.197	0.524	0.327
Significance	Not Significant	Not Significant	Not Significant

Different treatment methods brought negligible difference in mean scores among corresponding groups.

D. 3 Diagrams

Only question number 4 and 13 were considered as schematic diagram questions. These questions require students to explain different circuits that were connected in differently to their schematic representation using their symbols, or vice versa.

TABLE XV. Post test mean scores of DIRECT for schematic diagrams only.

Group	N	Mean	SD
REL	21	1.33	0.81
STC	22	1.09	0.61
SSC	21	1.29	0.56

Results of t-test performed between REL-STC, REL-SSC, and STC-SSC reveal a mean difference of 0.243 for REL-STC, 0.048 for REL-SSC and 0.195 for STC-SSC, a difference which is not statistically significant.

TABLE XVI. Results of unpaired t-tests between REL and STC, REL and SSC, and STC and SSC in diagram questions only.

	REL vs. STC	REL vs. SSC	STC vs. SSC
t-test	1.124	0.224	1.089
p-value	0.268	0.824	0.283
Df	41	40	41
Mean difference	0.243	0.048	0.195
Significance	Not Significant	Not Significant	Not Significant

D.4 Resistance

Question numbers 5, 21 and 27 were represented here. They need understanding of the concepts of resistance. They probe student's knowledge of the property of resistances and the resultant when they connected in series, parallel or combination of both.

TABLE XVII. Post test mean scores of DIRECT for resistance questions only.

Group	N	Mean	SD
REL	21	1.48	0.81
STC	22	1.95	0.72
SSC	21	2.05	0.8

Based on the results presented in Table XVIII, for resistance questions from DIRECT, no significant difference in mean scores was showed between simulations groups while there is a significant difference between REL & STC and REL & SSC. Computer simulations implemented either ways show dominance over real equipment.

TABLE XVIII. Results of unpaired t-tests between REL and STC, REL and SSC, and STC and SSC in resistance questions only.

	REL vs. STC	REL vs. SSC	STC vs. SSC
t-test	2.041	2.288	0.4
p-value	0.048	0.028	0.692
Df	41	40	41
Mean difference	0.478	0.571	0.093
Significance	Significant	Significant	Not Significant

D.5 Mixed

Question number 9, 10, 19 and 26 were taken as mixed questions. They sought the conceptual knowledge of students in every aspects of circuitry. They need the application of students' understanding in voltage, current, resistance and their interrelationships.

TABLE XIX. Post test mean scores of DIRECT for mixed questions only.

Group	N	Mean	SD
REL	21	1.52	1.17
STC	22	2.41	1.05
SSC	21	2.48	0.93

For mixed questions, the unpaired t-test results are given in Table XX. While there is a significant difference in the mean scores between REL-STC and REL-SSC group, there is no significant difference in mean scores for STC-SSC group.

TABLE XX. Results of unpaired t-tests between REL and STC, REL and SSC, and STC and SSC in mixed questions only.

	REL vs. STC	REL vs. SSC	STC vs. SSC
t-test	2.613	2.927	0.221
p-value	0.013	0.006	0.826
Df	41	40	41
Mean difference	0.885	0.952	0.067
Significance	Significant	Very Significant	Not Significant

Mixed questions need knowledge of electric currents, voltages, resistance and Kirchhoff's rule. A significant difference between each treatment groups was found.

E. Timing Data Results

The timing data is the time taken by group of students in each treatment group to build the circuit which is shown in Figure 1. One laboratory assistant of Damot preparatory school and the researcher were engaged in taking the amount of time students in each group needed to complete building the circuit. All three groups were divided in to seven groups as they did the experiment, except the STC group. For STC group, new seven groups were created, with each six groups had three students while the last group had four students. The average time for each treatment group are reported in Table XXI.

TABLE XXI. Post test mean scores of DIRECT for voltage questions only.

Group	N	Mean	SD
REL	21	15.171	1.334
STC	22	15.029	0.960
SSC	21	13.457	0.627

The mean time to finish building the circuit was 15.171 minutes for REL, 15.029 for STC group and 13.457 for SSC group.

TABLE XXII. Results of unpaired t-tests between REL and STC, REL and SSC, and STC and SSC in average time they took to construct Figure 1.

	REL vs. STC	REL vs. SSC	STC vs. SSC
t-test	0.229	2.924	3.541
p-value	0.883	0.013	0.004
Df	12	12	12
Mean difference	0.143	1.571	1.429
Significance	Not Significant	Significant	Very Significant

From Table XXII, it is shown that REL group is not significantly faster than STC, SSC group is significantly faster than REL group and SSC is significantly faster than STC group. SSC group scored fewer mean times to finish the construction of Figure 1.

V. DISCUSSION

The findings of this study suggest that real equipments can be replaced by simulation. Students who only watched the experiments when done via computers had better conceptual understanding of DC circuit than REL groups based on their result of DIRECT. They also showed that they can manipulate and use real instruments as did the real laboratory group. The finding of this study is consistent with the previous research of [5, 20, 7, 32].

The analysis of results from questions which represent current, resistance and mixed question items demonstrated that students from STC and SSC had a better mastery of these concepts in DC circuits. However, this difference in mastery was not observed for schematic diagrams and voltage questions.

The time data demonstrated that students who used simulations by themselves were more capable in building circuits using real equipment compared to those who watched and those who used real apparatus. SSC group took less average time in constructing the series-parallel circuit depicted in Figure 1. However the average times were found to be about the same for STC and REL groups.

Comparison of students post test performance with pre test shows that the DC experiment laboratory itself, whether students' watch when the DC experiment was done virtually or performed the same experiment using virtual or using real equipment promotes students conceptual capacities of the DC circuit. However, simulation practices in both cases were found to have facilitated better understanding of students in DC circuits.

It was found that simulations done by the teacher may promote students understanding and ability of using instruments better than mere lectures. Having two computers per school may provide students who are from schools without laboratory facilities to get the necessary knowledge and expertise of DC circuits.

VI. CONCLUSIONS

The main concern of this study was to investigate the effectiveness of computer simulations in substituting real equipment laboratories when implemented in student centered and teacher centered approaches. Because the research literatures on replacing real equipment labs with computer demonstration is not thoroughly investigated and the result is vital for to be applied in our context that economical constraints withhold fulfilling costly real lab equipment and computers in schools around the nation, this study was undertaken.

For three treatment groups (REL, STC, & SSC), two different effects on students were examined: achievement and skills of using lab equipments. Achievement was measured using a conceptual test called DIRECT. DIRECT is a conceptual test used to assess conceptual understanding of DC circuit? All three groups were assigned to build Figure 1 in groups of threes, and time taken to construct it in real lab was recorded to measure students' skills. Nine background questions were used to prove there was negligible difference among groups before this study.

There were difference found in achievement and skill of manipulating equipments between REL & STC, REL & SSC, and STC & SSC.

The first research question of this study was:

1. Will there be a significant difference in achievement based on DIRECT test between students in the simulation groups with different instruction settings and the real laboratory group?

This study focused on replacing real equipments by means of computer simulations in different teaching approaches and wanted to verify that this substitution does not harm student's achievement. For achievement, the t-test indicated that there were statistically significance difference between REL & STC, and REL & SSC but no difference was observed between STC & SSC.

Substituting the real equipments by computer simulations in student-centered and teacher-centered for DC experiment did affect the post test on DIRECT. The substitution brought positive difference.

The second research question of this study was:

2. Will students learn the same concept in simulation with teacher-centered and student-centered basis and real experiment in DC circuits?

This study also focused on the assertion that concepts of DC circuit learned by real equipments and computer simulations in different teaching setting are the same. Based on the subtopics presented, a statistical test was conducted.

For Current Questions Only

The t-test showed no statistical difference between the REL & STC groups, while statistical significance was found between REL & SSC and REL & STC. This may be due to the fact that students who did the DC experiment using simulation student centered instructional method had ample time to redo the experiment and also closely looked the motion of electrical charges motion, which are fundamental to the concept of current.

For Voltage Questions Only

The result of the t-test indicated no significant difference between each treatment groups. Replacing real labs with computer simulation did not affect students conceptual understanding of DC circuits.

For Schematic Diagram Questions Only

The t-test also indicates that treatments cannot make any difference on student's knowledge of interpreting and drawing of schematic diagrams. One reason for this may be only two questions were categorized as schematic diagram questions.

For Resistance Questions Only

As reported in Table 26, statistical significance was found in t-test between REL & SSC and REL & STC while no significant difference was observed between SSC & STC.

For Mixed Questions Only

T-test results show that, there was significance difference between REL & SSC and REL & STC but no significant difference was observed between SSC & STC.

The third research question of this study was:

3. Will students develop an ability of using real equipments though they do the experiment via computers for student-centered group and they watch when the experiment is done on the computer by the researcher for teacher-centered group?

Based on the time students took to construct Figure 1 using only real equipment, t-test was conducted. The result of the t-test demonstrated that no statistically significant difference was observed between REL & STC. But significant difference was observed between REL & STC and STC & SSC.

Though students from STC and SSC group did not use real equipment to perform the experiment, it had been found that they had at least a skill which was equal or better than those in the REL group. The substitution did not make students to lose the skill needed to manipulate real laboratory materials.

VII. RECOMMENDATIONS

It is valuable noting that it is still difficult to advice that simulations may substitute real equipment. But it was found that simulations done by the teacher may promote students understanding and ability of using instruments better than mere lectures. Having two computers per school may provide students who are from schools without laboratory facilities to get the necessary knowledge and expertise of DC circuits. Depending on the observations during this study computer simulations encourage contact and develop cooperation between students and faculty. It also promotes active learning by means of motivating students towards the subject. Simulations give prompt feedback on performance and lead as students to the specific task on time. It was seen that students from both simulation groups were interested, eager to participate and on-time during the course of the research.

1. The result of this study shows that computer simulations in different teaching approaches have pronounced impact in student's achievement score compared to REL, as well as their corresponding pretests. Physics teachers should think of the option simulation brought when they are in a position not is able to engage their students in the lab.

2. The result of this study shows that through REL group did their experiment using real equipment, SSC group outperformed in mastery of skills using real equipment.

Teacher should be aware of this, and especially apply it for experiments that may cause physical damages.

3. It will be advisable if further studies on computer simulations of this type will be conducted.

VIII. FUTURE RESEARCH SUGGESTIONS

This study was undergone in a laboratory setting for DC circuit experiments. Future studies could involve the effectiveness of the substitution of real labs by simulations in another topic in electricity or other parts of physics.

The use of computers is thought to help students build conceptual understanding of the physical concepts by providing visual model of the phenomena. So often in research studies, introductory physics are assessed. Thus, the use of computers in promoting learning gains in advanced physics courses could be studied. Additional studies are also needed which emphasize on the retention of the concept over a longer time following the use of computer simulations.

In the current study a gender issue was raised regarding the number of male and female participated in the study and across each treatment group. Additional studies are needed to further explore the difference in performance between male and female students.

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