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ABSTRACT

The study explored the effects of the interactive Physics Education Technology (PhET) simulation on conceptual understanding of Senior High School students on electricity concepts. The study employed the pre-test post-test non-equivalent control group design. A sample size of sixty-three (63) students from two schools participated in this study. The experimental group (School A) consisted of 32 students, and the control group (School B) consisted of 31 students. Intact classes were used. The electricity concept achievement test (ECAT) was the instrument used for data collection. It was revealed from the study that there was an improvement in conceptual understanding of students on "knowledge and understanding" and "application of knowledge" on electricity concepts taught with the PhET simulation in both a demonstrative classroom and an exploratory classroom (computer laboratory).

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ABSTRACT

The study explored the effects of the interactive Physics Education Technology (PhET) simulation on conceptual understanding of Senior High School students on electricity concepts. The study employed the pre-test post-test non-equivalent control group design. A sample size of sixty-three (63) students from two schools participated in this study. The experimental group (School A) consisted of 32 students, and the control group (School B) consisted of 31 students. Intact classes were used. The electricity concept achievement test (ECAT) was the instrument used for data collection. It was revealed from the study that there was an improvement in conceptual understanding of students on "knowledge and understanding" and "application of knowledge" on electricity concepts taught with the PhET simulation in both a demonstrative classroom and an exploratory classroom (computer laboratory). However, no significant difference was observed in students' conceptual understanding for students who were taught electricity concepts in a demonstrative classroom and those who were taught in an exploratory computer laboratory. It is therefore recommended that the PhET simulation should be used in teaching electricity concepts in physics either in a demonstrative classroom or in an exploratory classroom.

Keywords: demonstrative classroom, exploratory classroom, simulation assisted lessons, electricity, conceptual understanding.

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I. INTRODUCTION

Physics deals with the fundamental mechanisms underlying every phenomenon of the interactions of energy, matter, space and time (Urone & Henrichs, 2020, p. 7) and these phenomena forms the vital components of modern technology whose contributions have led to the development of products geared towards transforming modern day society (Cudjoe & Afram, 2018). Physics is therefore of great importance to development and hence, a keen interest must be taken in its teaching to enhance maximum understanding of concepts by learners which in turn will enable the "Ghanaian society function effectively in a scientific and technological era where many utilities require basic physics knowledge, skills and appropriate attitudes for operation" (MoE, 2010; p. ii).

However, these technological advancements have also influenced the teaching strategies as well as instructional resources employed by teachers in this computer age era (Voogt, 2003). Therefore, current teaching strategies and instructional resources must ensure active learner participation placing the teacher as a facilitator, making physics learning more practical and action-oriented as well as providing learner- friendly environment in order to enhance students' learning of concepts (Antwi & Sakyi-Hagan, 2015; Wieman, et. al., 2010; Mc Farlane, 2013). One of the instructional resources used in this computer age to maximise students' learning of physics concepts is the application of computer-based media (Gunawan, et. al., 2018) such as computer simulations (Agyei, Jita & Jita, 2019; Zacharia, 2007).

In the simulation environment, students visualise, study, replicate, and obtain rapid prompts regarding what is being studied, events, and complex phenomenon that requires a lot of time and is hazardous to take place in the classroom (Bell & Smetana, 2008). Simulation assisted lessons emphasise the constructivist ideology of teaching and learning since learners have the opportunity to come out with their own knowledge and are able to attach meaning to information provided (Strayer, 2016; Rehman et. al., 2021) and improves learners' physics understanding (Rehman et al., 2021; Zacharia, 2007).

Notwithstanding, the West African Examination Council (WAEC) examiners have expressed dissatisfaction towards students' performance in physics in external examinations in Ghana. A careful analysis of the WAEC chief examiners report on physics from 2015 to 2021 has indicated incorrect explanation of scientific phenomena, lack of understanding orcomprehension and application of knowledge in some theories in physics (WAEC, 2015; 2016; 2017; 2018; 2019; 2020; 2021) as the probable reasons that account for the low achievement of learners in the subject.

In addition to causes of students' poor performance highlighted by the chief examiner, research has also shown that factors that also account for students' poor performance in the subject include but not limited to perceived difficulty of the subject (Agyei & Agyei, 2021; Patel, 2018), teaching methods employed by teachers (Buabeng, Ampiah & Quarcoo-Nelson, 2012; Azure, 2015; Mekonnen, 2014), availability and adequacy of instructional materials (Fatoki, Iornyagh, & Ocheikwu, 2021), lack of understanding and application of mathematical skills in solving physics problem (Tuminaro & Redish, 2004; Semela, 2010); lack of reference materials, laboratory equipment, and interest in the subject (Mekonnen, 2014). It can therefore be inferred that the low achievement rate observed in physics as indicated by the chief examiner could also be from the outcome of previous literature.

The concepts in the physics curriculum where students' weaknesses were highlighted by the chief examiner include but not limited to projectile motion (WAEC, 2015), electronics (WAEC, 2015; 2016; 2017), sound (WAEC, 2020), optics (WAEC, 2017), heat (WAEC, 2018; 2020) as well as electricity (WAEC, 2015; 2017; 2018; 2019; 2020; 2021). From the analysis of the chief examiners' report, students' weaknesses in the area of electricity are almost highlighted every year.

The positive effects of PhET simulation make it a useful instructional resource that could be applicable for physics teaching and also offer support for students' learning. The problems identified by the chief examiner as the causes of students' poor performance in physics (electricity concepts) could be prevalent in almost every Senior High School that takes part in the examination in Ghana of which Senior High Schools in the South District of the Volta region are not excluded. For this reason, the study focused on exploring the influence of the interactive PhET simulation on students' conceptual understanding using Senior High Schools in the South Dayi district in the Volta region of Ghana. Specifically, the study was guided by the research question: What is the influence of simulation assisted lessons on students' conceptual understanding of electricity concepts taught in a demonstrative classroom and in an exploratory classroom (computer laboratory)?

II. LITERATURE REVIEW

Conceptual understanding according to Mc Dermott as cited by Banda and Nzabahimana (2021) can be defined as a "functional understanding or the logical capacity to apply knowledge in contexts or situations other than those in which it was generated or acquired". Conceptual understanding can be thought of as the capacity of a learner to apply ideas, explanations, connections, or representations in situations or settings that call for critical consideration (Banda & Nzabahimana, 2021). Banda and Nzabahimana (2021) further opined that conceptual understanding necessitates learners to combine information and knowledge acquired from established schemas and apply them in novel contexts. This implies that to develop a learner's conceptual understanding, then the learner must be able to link classroom experiences to real life situations. With improvement in a learner's conceptual understanding, the learner can see the application of physics concepts in daily life (Harrison & Gibbons, 2013).

In addition, physics instructors are expected to apply a variety of teaching methodologies to guarantee that students acquire conceptual knowledge and competence in science learning (Mbonyiryivuze et. al., 2019). Teachers should incorporate active learning strategies into the classroom in order to prepare students for the demands and expectations of the 21st century needs by way of establishing platforms which enhances the development of conceptual knowledge (Banda & Nzabahimana, 2021). This requires the 21st century teachers to be innovative and creative in their teaching methods with various technological tools that will enhance students' learning. Technological tools such as interactive simulations (Bo et. al., 2018) among others could facilitate students' learning of abstract physics concepts (Osborne & Hennessy, 2003).

Numerous physics simulations are available for purchase or free online. Among the available interactive simulations, PhET happens to be the one that is widely used (Zhang, 2014) since this simulation can be used in online and offline mode (Salame & Makki, 2021). According to Perkins, Moore and Chasteen as cited by Banda and Nzabahimana (2021), the PhET interactive simulations offers flexibility to usage, easily accessible and designed to meet a variety of learning goals due to the engaging and authentic platform it creates. This makes the PhET interactive simulation an instructional resource capable of enhancing students' learning of physics concepts and thus improve their conceptual understanding.

The enormous impact of the PhET interactive simulation on students' conceptual understanding and performance has been explored by several studies. Agyei and Agyei (2021) examined how using the PhET simulation improved pre-service university students' understanding of physics concepts. Since students enjoyed using the interactive simulation, evidence from the study showed improvement in students' understanding. The researchers recommended that the improved and enhanced learning could be brought about when learning activities with the interactive PhET simulation for content specific areas are done in an exploratory or in a demonstrative manner. In another study, the PhET was used as an instructional resource to teach "ohm's law" to ascertain how it will impact the performance of students on "ohm's law" (Ouahi et. al., 2021). The study's findings demonstrated that individuals who were taught "ohm's law" concepts with the PhET simulation had a better performance on the post-test items. The study by Rehman et al. (2021) looked into how students' conceptual compre- hension of physics concepts changed when high school physics was taught through intera- ctive simulation. It was evident from their findings that significant gains in students' conceptual understanding with a very high effect size was observed. Interview data from students also showed that the lesson taught with the PhET interactive simulation was interesting. The researchers recommended the application of PhET to facilitate physics instruction as it has the potential to reduce rote memorization of concepts by students.

Again, Prima et. al., (2018) explored how the use of the PhET simulation will enhance learner's understanding and motivate the learners to learn solar system concepts. The results of the study showed that students taught solar system concepts with simulation as a teaching media had better gains in conceptual understanding and motivation than their counterparts who were taught same concepts without the simulation. It was also revealed by the study that the use of the PhET simulation in teaching solar system concepts influenced students' conceptual understanding on "application of knowledge" more than "knowledge and understanding". All these literatures have highlighted the PhET interactive simulation as an instructional resource that can be used to enhance students' conceptual understanding of physics concepts.

III. RESEARCH METHODOLOGY

3.1 Research Design

The study employed the pre-test post-test non-equivalent quasi-experimental design. The quasi-experimental design is used when randomization of participants cannot be done by the researcher (Cohen, Manion & Morrison, 2018). In the present study, the categorisation of participants into control group and experimental group were not done by random assignment. Instead, intact classes were used.

3.2 Participants for the Study

The participants were sixty-three (63) first year students from two intact Physics classes from Senior High Schools in the South Dayi District in the Volta region of Ghana. The two schools were coded School A and School B respectively. Thirty-two (32) students were from School A and thirty-one (31) from School B. Students in School A were taught electricity concepts with the PhET simulation in a demonstrative classroom while students in School B were taught the same electricity concepts using the PhET simulation in an exploratory classroom. In the demonstrative classroom, the teacher projected the PhET simulation lesson to guide students' learning of the concepts taught, through demonstration and explanation of the concepts. This was because School A lacked computer laboratory facilities. In the exploratory classroom, students explored the PhET simulation themselves during and after regular class lessons to guide their learning of the concepts that were taught, with the assistance of the teacher.

3.3 Data Collection Instrument and Procedure

Electricity Concept Achievement Test (ECAT) was the instrument used for collecting data. Research shows that conceptual understanding test is widely used in physics (Gunawan et al., 2018) to measure students' learning outcomes (Rehman et al., 2021). The researcher developed the Electricity Concept Achievement Test (ECAT) based on the objectives stipulated for electricity in the 2010 physics syllabus for Senior High Schools in Ghana. The Electricity Concept Achievement Test (ECAT) consisted of twenty questions in all, including both objective and subjective questions measuring "Knowledge and Understanding (KU) and Application of Knowledge (AK)" of the profile dimension in the 2010 physics syllabus for Senior High Schools in Ghana. Eight questions measured knowledge and understanding dimension, whiles twelve questions measured application of knowledge dimension. Part I of the test was made up of fifteen multiple choice test items where participants were asked to choose a response from a list of plausible answers and Part II was made up of five open-ended test items where participants were to provide their own answers.

Both the multiple choice and open-ended test items were essentially intended to test participants' knowledge, understanding and application of knowledge in electricity concepts.

The test was given to students as pre-test before the intervention and as post-test after the intervention. According to Creswell and Creswell (2018), same test items could be used as pre-test and post-test since changing test items could influence the outcome of the scores. For this reason, same test items were used for both the pre-test and post-test. However, Creswell and Creswell emphasised that to avoid participants from becoming familiar with the test items, the researcher must ensure that there is a longer time interval between the administration of the test items. To avoid participants from becoming familiar with the test items, the post-test was administered four weeks after administering the pre-test.

The reliability of the test instruments was determined using the test-retest reliability procedure. Using this approach, the researchers administered the Electricity Concept Achievement test (ECAT) to a whole class with thirty students in a school in the district which did not participate in the study and after two weeks re-administered the Electricity Concept Achievement test (ECAT) to the class again. Pearson correlation coefficient (r) was used to score and correlate participants' responses for both Electricity Concept Achievement Tests (ECAT) and the value was found to be 0.82 which shows the test items were reliable (Cohen, 1988).

IV. DATA ANALYSIS

Data was analysed using both descriptive and inferential statistics. Descriptive statistics such as means and standard deviations were employed. Also, inferential statistics, such as independent samples t-test and paired samples t-test were performed to ascertain any significant difference in the scores of the School A and School B at 5% significance level. The effect size (eta squared) was also calculated to ascertain the extent to which the use of the interactive PhET simulation influenced students' conceptual understanding on electricity concepts. According to Cohen (1988), eta squared value of 0.01 shows a small effect, 0.06 shows a moderate effect and 0.14 shows a large effect.

V. RESULTS

An independent sample t-test at a confidence level of 95% was used to test the level of significant difference between the pre-test scores of Schools A and B. The results were presented in Table 1.

Table 1: Independent Sample t-test for Pre-Test Scores of Schools A and B

School	*N*	*M*	*SD*	*df*	*t*	*p*
School A	32	5.75	2.57	61	0.424	0.673
School B	31	6.00	2.06			

There was no significant difference between the mean scores of School B (M = 6.00, S.D. = 2.06) and School A (M = 5.75, S.D. = 2.57); t (61) = 0.424, p = 0.673. This implies that both schools were characteristically similar in their conceptual understanding on electricity concepts before the intervention.

To find out the impact of the PhET interactive simulation in a demonstrative classroom and in an exploratory classroom on students conceptual understanding of electricity concepts, means, standard deviations, paired sample t-test, as well as independent sample t-test were performed. Descriptive statistics of the pre-test and post-test analysis of the scores of Schools A and B are presented in Table 2, whiles the results of the analysis of the scores of the t-test are presented in Table 3.

Table 2: Mean scores difference between Schools A and B on the ECAT Pre-Test and Post-Test

School	*N*	ECAT	M	*SD*
School A	32	Pre-Test	5.75	2.57
		Post-Test	24.37	5.06
School B	31	Pre-Test	6.00	2.06
		Post-Test	25.54	5.01

Generally, it was evident that, there was a huge improvement in students' conceptual understanding on electricity concepts after they were taught the concepts with the PhET interactive simulation in the demonstrative classroom and in an exploratory classroom, as shown in Table 2. It was also observed that School B performed better than School A as evidenced by the difference in mean scores on the post-test in Table 2.

A paired sample t-test at a 95% confidence level of the pre-test and the post-test scores of students in Schools A and B showed that there was a significant difference between pre-test and the post-test scores of students in Schools A and B as shown in Table 3. Statistically, there was a significant difference between the mean scores on the pre-test and post-test scores. The p-value of 0.000 which was less than 0.05 showed there was a significant difference in students' conceptual understanding on electricity concepts. The effect size of 0.958 for School A showed that there was a large variation between the pre-test and the post-test scores. The eta squared value obtained, meant that about 95.8% of the difference in the post-test scores could be accounted for by the use of the PhET simulation in a demonstrative classroom.

Again, it was observed that statistically there was also a significant difference between the mean scores on the pre-test and the post-test for students in School B who had the lesson in an exploratory classroom. The effect size of 0.973 showed a large variation between the two scores and this suggested that the significant difference observed in students' conceptual understanding could be attributed to the use of the PhET interactive simulation used in the exploratory classroom lesson delivery.

Table 3: Paired sample t-test of students in School A and B on the ECAT Pre-test and Post-test

School	*N*		M	*SD*	*p*	η2
School A	32	Pre-test	5.75	2.57	0.000	0.958
		Post-test	24.37	5.06		
School B	31	Pre-test	6.00	2.06	0.000	0.973
		Post-test	25.54	5.01		

An independent sample t-test at a 95% confidence, as shown in Table 4, a p-value = 0.359 > 0.05, meant that there was no statistically significant difference between the mean scores on the post-test scores for students in Schools A and School B.

Table 4: Independent Sample t-test for Post-Test Scores of Schools A and B

School	*N*	*M*	*SD*	*P*
School A	32	24.37	5.06	0.359
School B	31	25.54	5.01	

This implied that the PhET exploratory and demonstrative classroom simulations both similarly influenced students' conceptual understanding on electricity concepts.

For the individual profile dimensions of "knowledge and understanding (KU)" and "application of knowledge (AK)", a paired sample t-test at a confidence level of 95%, as shown in Table 5, revealed that statistically, there was significant difference in students conceptual understanding on KU and AK, at Schools A and B.

The eta square values of 0.931 and 0.957 respectively for Schools A and B, showed that the use of the PhET simulation in an exploratory classroom influenced concepts of KU more than in a demonstrative classroom. Again, the eta square values of 0.876 and 0.929 respectively for Schools A and B, showed that the use of the PhET simulation in an exploratory classroom influenced concepts of AK more than in a demonstrative classroom.

Table 5: Paired Sample t-test on the Profile Dimensions "Knowledge and Understanding (KU)" and "Application of Knowledge (AK)" for Schools A and B After the Intervention

Profile dimension	*N*		*M*	Mean Diff.	*SD*	p	η2
KU of School A	32	Pretest	3.06	8.218	2.268	0.000	0.931
		Posttest	11.28				
KU of School B	31	Pretest	3.12	8.419	1.803	0.000	0.957
		Posttest	11.54				
AK of School A	32	Pretest	2.68	10.093	3.855	0.000	0.876
		Posttest	12.78				
AK of School B	31	Pretest	2.90	11.096	3.399	0.000	0.929
		Posttest	14.00				

It was however evident from the independent sample t-test (Table 6) that the differences in the mean scores observed on KU and AK for the two schools were not significant.

Table 6: Independent Sample t-test on the Profile Dimensions "Knowledge and Understanding (KU)" and "Application of Knowledge (AK)" for Schools A and B After the Intervention

Profile Dimension	School	*N*	*M*	*SD*	*df*	*t*	*P*
Knowledge and understanding	A	32	11.28	1.59	61	0.646	0.521
	B	31	11.54	1.68			
Application of Knowledge	A	32	12.78	4.01	61	1.212	0.230
	B	31	14.00	3.97			

VI. DISCUSSION OF RESULTS

The study sought to examine the influence of simulation assisted lessons on Senior High School students' learning outcomes in electricity concepts when they are taught these concepts in a demonstrative classroom (in a non-computer laboratory) and in an exploratory classroom (in a computer laboratory) using the interactive PhET simulation as a teaching and learning resource.

In examining the impact of the use of the interactive simulation on students' conceptual understanding, a paired sample t-test (Table 3) showed there was a significant difference between students' pre-test scores and post-test scores on the conceptual understanding of all students in the two schools that participated in the study.

This suggested that generally, the use of the interactive PhET simulation in teaching electricity concepts in a computer laboratory or in a non-computer laboratory influenced students conceptual understanding and this finding was in line with previous studies (Agyei & Agyei, 2021; Ouahi et. al., 2021; Rehman et. al., 2021, Agyei et. al., 2019; Wang et. al., 2010 Zecharia, 2007), who found that the use of the PhET interactive simulation has the potential to improve students' learning outcomes and conceptual gains since it offers students an interactive platform to learn (Fan, 2015; Zulfiqar et al., 2018).

For the profile dimensions of "knowledge and understanding' (KU) and "application of knowledge" (AK), there was a significant difference in students' conceptual understanding, (Table 5). The study revealed that the exploratory classroom influenced students' "knowledge and understanding" more than "application of knowledge", even though independent sample t-test (Table 6) showed that the differences in the mean scores observed on KU and AK for the two schools were not significant. This finding however contradicted with the findings of Prima et. al. (2018) who found that the use of the PhET interactive simulation influenced students' "application of knowledge" more than "knowledge and understanding". This could be due to the differences in physics concepts that was used in the study by Prima et. al. (2018).

Again, an independent sample t-test (Table 4) indicated that statistically there was no significant difference between the mean scores of students taught with the simulation in the demonstrative classroom and those taught in an exploratory classroom. This finding corroborated with the findings of Agyei and Agyei (2021) who opined that the use of the interactive PhET simulation in teaching physics concepts was effective in a demonstrative and an exploratory classroom on concepts in electricity. This could be due to the fact that students in the demonstrative classroom were not given the opportunity to explore the PhET simulation themselves (Agyei & Agyei, 2021). This finding suggested that the PhET simulation use in teaching should preferably be done in the computer laboratory but using it in a demonstrative manner in the classroom could also lead to a significant gain in students conceptual understanding on "knowledge and understanding" and "application of knowledge".

VII. RECOMMENDATION

Teaching electricity concepts with the PhET interactive simulation influenced students' conceptual understanding on "knowledge and understanding" and "application of knowledge" for students in all three schools. However, no significant changes were observed between the mean scores of students taught the concepts in the demonstrative classroom and those taught in an exploratory classroom (computer laboratory). It is therefore recommended that physics educators should utilise the PhET as an instructional resource for teaching electricity concepts in physics either in a demonstrative classroom or in an exploratory classroom.

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