American Journal of Educational Research, 2018, Vol. 6, No. 8, 1172-1181
Available online at http://pubs.sciepub.com/education/6/8/16

DOI:10.12691/education-6-8-16

Combining Inquiry-Based Hands-On and Simulation Methods with Cooperative Learning on Students' Learning Outcomes in Electric Circuits

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Received July 05, 2018; Revised August 07, 2018; Accepted August 17, 2018

Abstract Concepts in electric circuits are reported in literature as being problematic for students at all levels of pre-tertiary education [1] and the situation in Ghana is not different [2]. Hence, innovative ways of teaching are being explored by researchers to remediate the problem. This study, therefore, was premised on the fact that combining inquiry-based real hands-on and computer simulation methods with cooperative learning has the potential of improving students' learning outcomes. In all, 110 senior high school Form 2 students from two schools who participated were put into heterogeneous-ability and friendship cooperative learning groupings. Each group was taught electric circuits with the combination of inquiry-based real hands-on and computer simulation method. The aim was to compare the two groups in terms of their scientific reasoning and conceptual understanding. Within each group, the hypothetical-deductive and empirical-inductive students were also compared along the two learning outcomes. The results showed among others that the heterogeneous-ability group outperformed their counterparts in conceptual understanding of electric circuits but not scientific reasoning. Hypothetical-deductive and empirical-inductive students in the heterogeneous-ability group outperformed their counterparts in scientific reasoning and conceptual understanding. Implications of the findings for teaching and learning are discussed.

Keywords: *learning outcome, scientific reasoning, hypothetical-deductive reasoning, empirical-inductive reasoning, conceptual understanding*

Cite This Article: Godwin Kwame Aboagye, Theophilus Aquinas Ossei-Anto, and Joseph Ghartey Ampiah, "Combining Inquiry-Based Hands-On and Simulation Methods with Cooperative Learning on Students' Learning Outcomes in Electric Circuits." *American Journal of Educational Research*, vol. 6, no. 8 (2018): 1172-1181. doi: 10.12691/education-6-8-16.

1. Introduction

Researchers and educators in the science education community have developed curricula, methods and practices to improve concept development by focusing on students' learning outcomes. These learning outcomes, defined as the knowledge, skills, and abilities that students attain as a result of their involvement in a particular set of educational experiences, include students' conceptual understanding, scientific reasoning and conceptual change [3,4]. For the purpose of this study, learning outcomes is restricted to conceptual understanding and scientific reasoning. Conceptual understanding, in this context, is the ability of students to apply the concepts learned in novel situations to solve problems, make judgements and inferences [5] while scientific reasoning is the mental process that involves using and applying knowledge or patterns of thought to solve problems, make decisions and achieve goals efficiently [6]. Studies on the developmental view claim that effective concept development is primarily dependent on students' reasoning ability and that the ability to reason have been found to be the strongest prognosticator of meaningful understanding of concepts in science [7,8]. A number of studies have also found that students who lack acceptable reasoning skills perform more abysmally on measures of conceptual understanding [5,9]. This means the higher the ability of a person to think in an abstract way, the higher the person will function effectively in society [10]. Hence, concentrating on improving formal reasoning and thinking abilities among students should be one of the most important aims of science education at all levels of education.

Several concepts in science-related subjects, especially physics, have been problematic for students to comprehend and apply them efficiently in new situations when the need arises [2]. The difficulties students encounter with formal concepts relate to their inability to apply scientific reasoning skills that are essential ingredients necessary for explaining scientific concepts [8]. For instance, electric circuits, a topic in direct current electricity, is one of the topics that have been found to be more challenging for students at all levels of education to understand since it requires the understanding of the behaviour of particles at the microscopic level [11,12]. The central concepts, such as voltage, current and resistance, are difficult, complex and abstract by nature and so require the application of hypothetical-deductive thought to aid understanding [13,13]. Students also have difficulties when they are required to apply concepts and principles of electric circuits [15,16,17,18,19]. Some of the difficulties students face in electric circuit identified were: their inability to draw electric circuits and interpret them; and poorly conducted experiment to determine the resistivity of a wire [15]; students inability to apply Kirchhoff's law to solve simple questions [18]; most students could not establish that resistance is inversely proportional to current [17]; majority of the candidates failed to recognise the relationship between resistance and the balance length on a metre bridge [16,19]. These difficulties clearly show that concepts in electric circuits are problematic for students to grasp and efforts need to be made to address these problems. Again, sound development of concepts in electric circuits forms the basis for understanding other higher topics like electrical energy, capacitance, alternating current theory, magnetic fields, electromagnetic induction, electronics, photo-electricity as well as many topics in other science related subjects [2]. This, undoubtedly, makes electric circuits a critical topic which needs to be taught and developed adequately in order to improve students' performance in physics.

The cognitive development theory developed by Jean Piaget, though criticised and revised [20,21], conceptualised four different stages in the cognitive development of a person – sensorimotor (0 – 2 years), preoperational (2 – 7 years), concrete operational (7 – 11 years), and formal operational (11 – 16 years) [6]. The main difference among these stages is the mode of scientific thinking. According to [22], the latter two stages of Piaget's theory are relevant to scientific reasoning, simply, because advanced scientific reasoning skills begin to develop at these stages. [23] later, renamed concrete operational stage as empirical-inductive (EI) thought and the formal operational stage as hypothetical-deductive (HD) thought. EI thinking pattern involves conservational reasoning where students operate on the assumption that 'I see, I believe and I know' (i. e., applies conservation thinking to perceptible objects and properties or unobservable entities) while HD thought, on the other hand, involves skills associated with testing hypotheses about observable causal agents [22]. HD reasoning is important in concept development since it involves experimentation where students test their preconceptions against scientific concepts and find out which one match experimental results [7,24]. Researchers [3,7,22,23] have identified five different scientific thinking patterns to include: proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. Surprisingly, formal thought begins to develop at the age of 11 or 12 years and reaches an equilibrium state at around age 15 or 16 years where majority of the students would be in senior high school. However, studies have shown that majority of senior high school students operate at the concrete stage of reasoning when given cognitive tasks [10,22] and also as many as 50% of students in college level biology do not engage in higher order scientific reasoning [23]. This shows that a good number of students at high school level are still operating at EI level and so innovative teaching strategies need to be used to promote HD thinking. It is also very important for teachers to identify the EI and HD students in their classes in order to monitor their progress during instruction.

Researchers [2,25,26] have used different teaching methods to solve the difficulties associated with electric circuits. However, it appears inquiry-based real hands-on laboratory method and inquiry-based computer simulation method have gained the most popularity in helping to solve these problems to an extent [27,28,29,30]. Advocates of real hands-on laboratory method have emphasised typically the importance of authentic experiences to foster student learning while those of computer simulations have argued that it is the active manipulation, rather than the physicality that is the most important element of instruction and that simulations aid students in understanding microscopic processes. Even though computer simulations alone have been used to promote scientific reasoning and conceptual understanding of electric circuits in other developed countries [3,28,29], it may not always be the case when it comes to most developing countries. This is because not all the schools in developing countries have access to electricity, computer laboratories and simulation software. Again, since research findings are always affected by the context of the study [31], it is critical to consider the educational system in any country and what is required of students during their final examinations before attempts are made to prescribe any solution to the difficulties students encounter in electric circuits. At the senior high school level in West African countries, for instance, students are made to perform real hands-on electric circuit practicals during the final examinations at the West African Senior Secondary Certificate Examination level and students do not use computers during their practical examinations. However, it is important to include computer simulation activities in teaching electric circuits at the high schools since in may help students understand the abstract principles and concepts underlying the real hands-on activities. The idea is that there might be added value in combining both real hands-on laboratory and computer simulation methods in order to fill in the gaps that either of the methods may present instead of teaching using either of the methods alone in the domain of electric circuits [32,33,34,35]. Although these studies showed improvement in student learning in favour of the combination of simulation and real hands-on laboratory activities as compared to either real hands-on laboratory alone or simulation alone, it appears time for instruction as a variable was not controlled. Thus, the combinational groups had an added advantage over the other groups which in effect may affect the findings and conclusions of those studies. The combinational groups appear to have used more time than their counterparts even though all the groups covered the same content materials. Again, the combinational groups had double treatments (i.e., both real and simulation activities) while the real hands-on laboratory only and simulation only groups had a single treatment which further gave the combinational groups added advantage. The difference in time spent for instruction and equivalence in terms of number of methods used for instruction could not be accounted for by these studies. There is, therefore, the need for a study to be conducted in which students will be given equal opportunities in terms of time spent for instruction and mode of treatments in all studies when using the combination of inquiry-based real hands-on laboratory and computer simulation methods. This study, therefore, seeks to fill this gap in the science education literature.

How should these combinational activities be carried out in the classroom for effective teaching and learning to take place? Cooperative learning has proven to have the potential of serving as a medium for other teaching methods like the combination of inquiry-based real hands-on and computer simulation activities in achieving higher learning outcomes [36,37]. This is because in cooperative learning, a low-ability individual (EI student) is better able to develop a more complex level of understanding and reasoning through collaboration with an able high-ability peer (HD student) than could have been done individualistically [3,38]. Although cooperative learning has been used successfully in achieving educational goals, research in science education still questions its efficacy in terms of the type of group composition [3,39]. Some research findings have advocated for the use of friendship and heterogeneous-ability group compositions based on their enormous strengths [3,37]. Though various researches have shown the importance of friendship and heterogeneous-ability groupings in promoting students' conceptual understanding and scientific reasoning, little attention has been paid to their effects in helping EI students move toward HD thought. It also appears very few studies, if any, have been conducted to investigate the effects of combining inquiry-based real hands-on laboratory and computer simulation methods with two cooperative learning groupings (i.e., heterogeneous-ability cooperative learning grouping and friendship cooperative learning grouping) on students' scientific reasoning and conceptual understanding of electric circuits. This study, therefore, ascertained the extent to which the combination of inquiry-based real hands-on and computer simulation methods would affect senior high school students' scientific reasoning and conceptual understanding of electric circuits when the students are organised in two types of cooperative learning groupings (i.e., heterogeneous-ability cooperative learning [HACL] grouping and friendship cooperative learning [FCL] grouping). Based on evidence in related literature, the following null hypotheses were tested at Bonferroni adjusted alpha level of significance of .025:

1. There is no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between senior high school [SHS] students taught using the combination of inquiry-based real hands-on and computer simulation methods with heterogeneous-ability cooperative learning [HACL] grouping and those taught using the combination of inquiry-based real hands-on and computer simulation methods with friendship cooperative learning [FCL] grouping.
2. There is no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between HD SHS students using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping and those taught using the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping.
3. There is no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between EI SHS students taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping and those taught using the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping.

2. Theoretical Framework

Research on students' learning has long been an important factor in all teachers' instructional theory and any instructional strategy used to facilitate students' learning should be capable of yielding desired learning outcomes. Although different approaches exist, combination of inquiry-based real hands-on laboratory and computer simulation methods through the use of cooperative learning appear to have the potential of yielding these learning outcomes. The combinational inquiry-based method used in this study followed the 3-E inquiry-based learning cycle model. This 3-E inquiry-based learning cycle model is based on well-known theoretical frameworks from science education and cognitive psychology theories that emphasis cognitive development and individual interaction with the environment [40], and social interaction [41].

[40] proposed that learning occurs through an individual's active social interaction with the environment and that the individual passes through different stages of development, each characterised by the ability to perform various cognitive tasks. The most important stages for science education are the concrete and formal operational stages of reasoning, since mental functioning or operations exist at these stages. Though the concept of the stages of concrete and formal reasoning has been criticised and revised, studies have demonstrated that as measured by performance on cognitive tasks, the majority of secondary school students are at the concrete stage of reasoning [10,22]. Piaget believed that the intellectual development of students toward formal reasoning could be facilitated through four stages of mental functioning: assimilation, disequilibrium, accommodation and reorganisation. [41] also believed that social interaction among students and their peers enables them to extend their knowledge than working individually. He indicated that there is a hypothetical region (i.e., zone of proximal development) where learning and development best take place. Both Piaget and Vygotsky saw cooperative learning with more able peers and instructor as resulting in cognitive development and intellectual growth. Based on these two theories, a theoretical model of this study is presented in Figure 1.

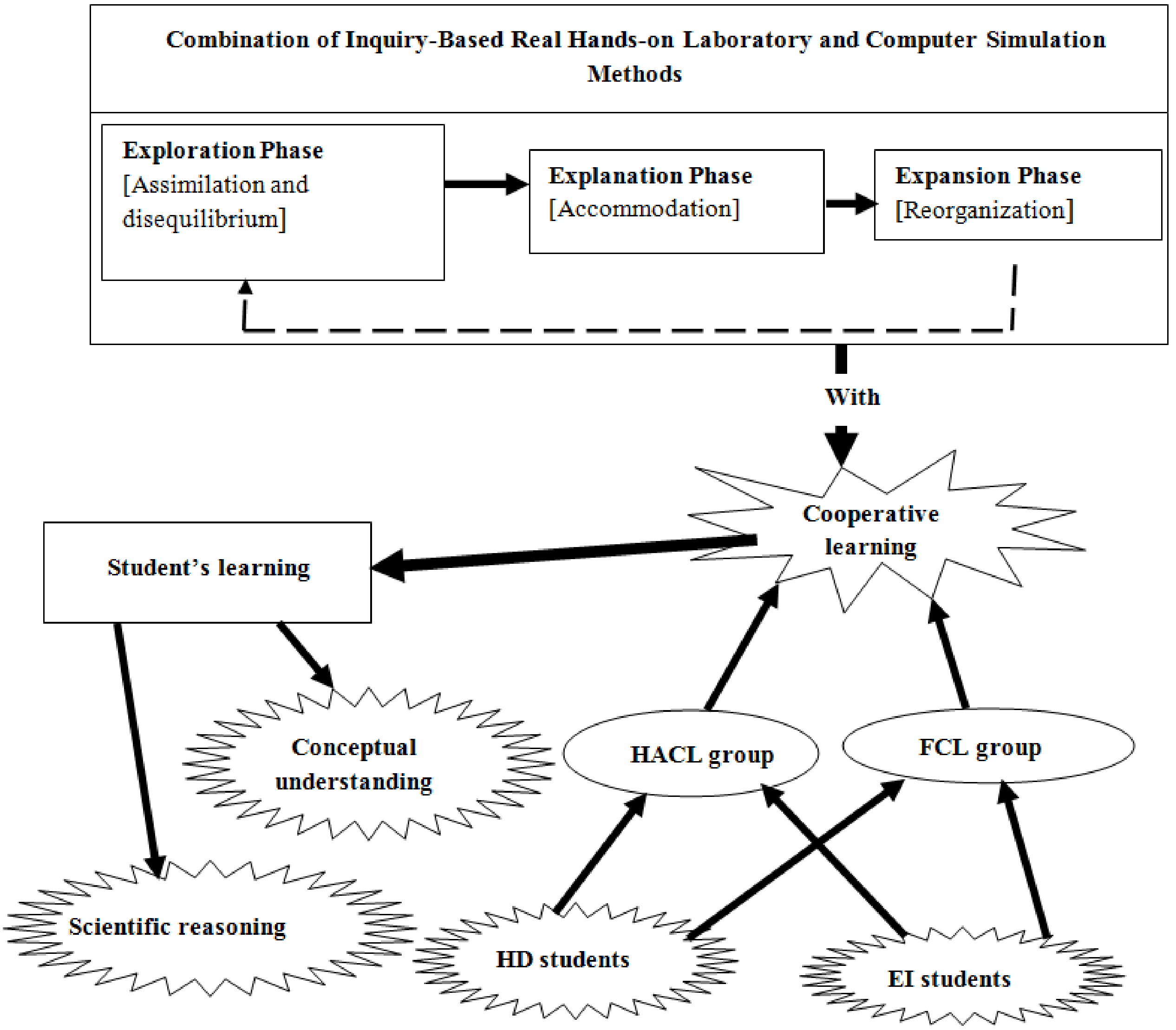

Figure 1. Theoretical model of the study

The phases in 3-E inquiry-based learning cycle can promote conceptual understanding and scientific reasoning in the following ways. The exploration phase of the 3-E inquiry-based learning cycle promotes assimilation by giving students an opportunity to make predictions, provide explanations, perform experiment, confront dissonance and attempt to construct a more scientific view of concepts. When the new information assimilated does not fit into an existing mental structure, disequilibrium or cognitive conflict occurs. As a result, students are required to resolve their cognitive conflict through the inquiry-based activities and peer support in cooperative learning. This can cause new schemes to be built or structures to be modified, to enable an altered structure to emerge. Accommodation occurs in the explanation phase and is as a result of disequilibrium. The explanation phase allows students to accommodate or construct new mental structures. The new mental structures allow for the development and understanding of the new concepts derived from the exploration phase.

The expansion phase provides additional experiences that may aid students to discover further applications of newly developed concepts and principles, providing opportunities for reorganization to occur. Students are encouraged to identify patterns, discover relationships among variables and reason through new problems. This provides an opportunity for students to apply the mental set or new concepts learnt to a new situation to ensure that successful conceptual understanding and scientific reasoning have occurred. The expansion of the ideas may involve additional laboratory experiences, demonstrations, readings, questions, and/or problem sets and this will require the whole cycle to start over again. In this study, heterogeneous-ability cooperative learning [HACL] and friendship cooperative learning [FCL] groupings were used with the combinational inquiry-based method to promote students' conceptual understanding and scientific reasoning. Research indicates that in adolescent classrooms such as those used in this study, there is high possibility of finding both empirical-inductive [EI] (concrete operational) and hypothetical-deductive [HD] (formal operational) reasoning students learning together and their progress needs to be followed [3,42]. With this, Piaget and Vygotsky believe that the EI students benefit from the immediate feedback and individual guidance that the HD students provide in the form of hints and strategies, which further develop the EI students' ability towards hypothetical-deductive reasoning.

3. Methodology

3.1. Research Design

The main aim of this study was to investigate the extent to which the combination of inquiry-based real hands-on and computer simulation methods would affect Form 2 senior high school students' scientific reasoning levels and conceptual understanding of electric circuits when the students are organised in two types of cooperative learning groupings (i.e., HACL and FCL groupings). Based on this aim, the study adopted a quasi-experimental design (i.e., specifically, the pretest-posttest non-equivalent groups treatment design) [43,44]. In order to implement this design, two existing intact classes from two different senior high schools were randomly assigned and designated as Experimental Group 1 and Experimental Group 2. The Experimental Group 1 (i.e., HACL group) was taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping and the Experimental Group 2 (i.e., FCL group) were taught using the combination of inquiry-based real hands-on laboratory and computer simulation methods with FCL grouping. Since the two groups were taught using the combination of inquiry-based real hands-on and computer simulation methods, the difference in instruction between the two groups was the method of grouping. Therefore, any change in students' learning outcomes should be attributed to the methods of cooperative learning groupings formed (i.e., HACL grouping method and FCL grouping method).

This quasi-experimental design study also employed a 2 x 2 Factorial Design since the study also sought to investigate the effects of the independent variable on the dependent variable at each of the two levels of the moderator variable. The independent variable in this study was the instructional method at two levels: Combination of inquiry-based real hands-on and computer simulation methods with HACL grouping (i.e., HACL grouping method) and combination of inquiry-based real hands-on and computer simulation methods with FCL grouping (i.e., FCL grouping method). The dependent variable in this study was also at two levels. The two levels of the dependent variable were the students' conceptual understanding (CU) and students' scientific reasoning (SR) ability. The moderator variable was the students' scientific reasoning level which was designated as either Empirical-Inductive (EI) or Hypothetical-Deductive (HD) level. The reason for using the factorial design was to allow the researcher to investigate the effects of two different instructional methods and students' scientific reasoning levels on a set of dependent variables and to determine whether the effects of the instructional methods were specific to particular scientific reasoning level [45]. The factorial design of the study is illustrated in Figure 2.

3.2. Research instruments

The study used two main instruments for data collection. The first instrument used was an achievement test called Current Electricity Concepts Achievement Test (CECAT) developed by [2] with a reliability coefficient of 0.76 using KR-20 formula. CECAT was used to test the conceptual understanding of students in all the concepts in electric circuits. It tested the ability of students to apply the concepts in electric circuits to solve problems in novel situations. CECAT was adapted and used for pretest and posttest. It consists of thirty multiple-choice test items. In developing CECAT, a set of instructional objectives were constructed from subtopics treated under electric circuits in the senior high school physics syllabus and textbooks as follows: physical aspects of electric circuits, current, potential difference, and combination of current and voltage. The second instrument was the Group Assessment of Logical Thinking Test (GALT) developed by [46] to measure students' level of scientific reasoning abilities under the following subscales: conservational reasoning, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. GALT was adapted and used to measure the students' level of reasoning abilities. GALT was deemed appropriate because it is capable of indicating the reasoning abilities of students at all levels just like other logical thinking instruments like Lawson's revised Classroom Test of Scientific Reasoning Skills (CTRS) and Test of Logical Thinking Ability (TOLT). GALT consists of 12 items which uses a two-tier multiple choice response format for presenting options for answers as well as the justification or reason for that answer. The choice of a correct option and a correct reason attracted a score of 1 mark but the choice of a correct option and a wrong reason attracted a score of 0.

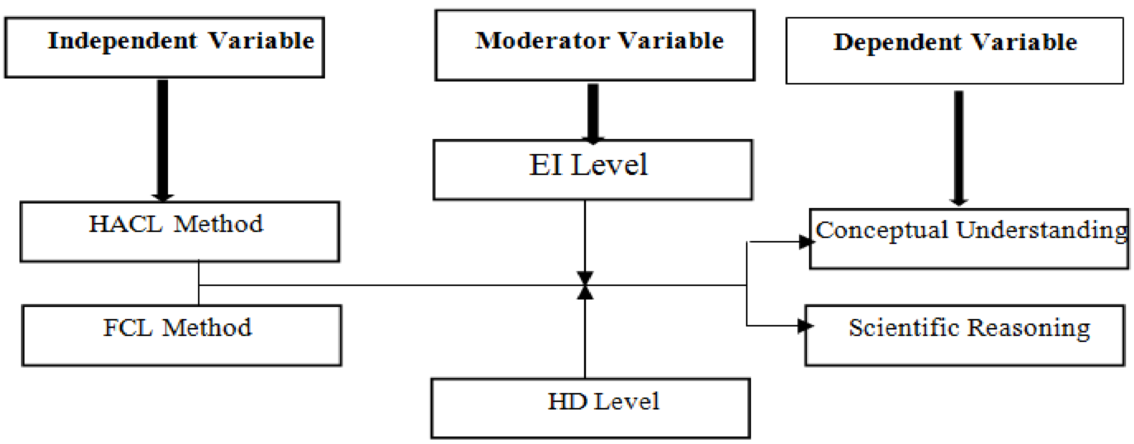

Figure 2. Factorial design of the study

3.3. Sampling Procedure

The sample consisted of 110 Form 2 students in two intact classes selected from two different SHS in the Cape Coast Metropolis, Ghana. The average age of the students in the two classes used was 16.5 year. Computer generated random numbers was used to randomly select two schools out of the 10 SHS offering physics, chemistry, biology and mathematics as elective to participate in the study. Two schools were selected because the study sought to investigate the effect of two methods on students understanding of concepts in electric circuits. One intact science class each out of the three science classes found in the two schools were further randomly sampled using the computer generated random numbers to participate in the study. The choice of the HACL and the FCL groups was further determined by random sampling. The HACL group consisted of 55 students and the FCL group also consisted of 55 students. The sample size for each group meets the statistical power criterion of .8 with alpha level of .05 for a large effect size of .8 [37].

The HD and EI students in the HACL and FCL groups were determined based on the scores they obtained after the Group Assessment of Logical Thinking Test (GALT) was administered at the pretest stage. Students who obtained scores of 0 to 6 were considered as EI students and students with scores from 7 to 12 were considered as HD students [42]. After pretesting GALT, the HD and EI students in the HACL group were 21(38.2%) and 34(61.8%) respectively and the HD and EI students in the FCL group were 23(41.8%) and 32(58.2%) respectively. These show that there is quite a good number of students with formal scientific reasoning at SHS Form 2. In all, there were 13 heterogeneous-ability groups formed from the 55 students in the HACL group, with 12 out of the 13 groups having four members and one group with five students. The students in the FCL group were made to choose members of their class with whom they most preferred or desired to work together with and they maintained their groups throughout the study. A careful examination of the groups formed by the FCL group revealed that out of the 13 groups formed, four of the groups comprised of EI students only, five of the groups comprised of HD students only and four of the groups comprised of heterogeneous-ability members.

3.4. Description of the Material and Inquiry-based Model Used

In this study, all the two groups received the same instructional packages. During the intervention, students were first exposed to computer simulations activities and reinforced by real hands-on laboratory activities in every lesson. The computer simulation software that was used is called Circuit Construction Kit (CCK) developed by Physics Education Technology (PhET), University of Colorado at Boulder. This is a free software available to science teachers and researchers online. The students were given instructions on how to use CCK and asked to explore the different parts of the simulation. CCK provides students with the opportunity to manipulated parameters and make necessary observations. Each group of students performed given sets of experiments using prescribed instructions provided on electric circuits.

The inquiry-based teaching activities were administered in six separate sessions for each of the two groups. The combination of inquiry-based real hands-on laboratory and computer simulation methods (i.e., intervention) used for this study followed the 3-E inquiry-based learning cycle teaching model which uses three essential phases. The concepts taught include: Elements of simple electric circuits; Ohm's law; Cells connected in series; Cells connected in parallel; Resistors connected in series; and Resistors connected in parallel. Two days after the end of the teaching session six in each school, the entire classes in all group conditions were given CECAT and GALT as posttest to determine their understanding and scientific reasoning respectively.

4. Results

All hypotheses were tested at Bonferroni adjusted alpha level of significance of .025.

4.1. Pre-experimental Results

Pre-experimental screening tests showed no violation of all multivariate assumptions of multivariate analysis of variance (MANOVA) for normality, linearity and multicollinearity, multivariate outliers and multivariate normality, homogeneity of covariance matrices and test of equality of error variance across the two groups' pretest mean scores. Pillai's Trace criterion was used to evaluate the multivariate differences since it is considered to have the acceptable power and the most robust statistic against violations of assumptions [i.e., it offers protection against Type I errors with small sample sizes] [37]. As shown in Table 1, the results of MANOVA indicated that HD and EI students in the HACL and FCL groups were equivalent in scientific reasoning and conception understanding of electric circuits.

4.2. Experimental Study Results

Since there were no statistically significant differences in the two groups' mean scores in pre-SR and pre-CU at the pre-experimental results for the group effect, HD and EI students, MANOVA was performed to investigate the differences in performance of students in the posttest mean scores. Assumption testing was again conducted to check for normality, linearity and multicollinearity, multivariate outliers and multivariate normality, homogeneity of covariance matrices and test of equality of error variance and no violations were observed. Table 2 shows the summary of MANOVA results on scientific reasoning and conceptual understanding of electric circuits for posttest scores. As shown on Table 2, there was a statistically significant difference in mean scores between HACL and FCL groups on the combined dependent variables ($p < .001$).

There were also statistically significant difference in mean scores between HD and EI students for the HACL and FCL groups respectively on the combined dependent variables. This means the type of instructional method (i. e. HACL and FCL methods) used for instruction significantly influenced or improved students' scientific reasoning and conceptual understanding of electric circuits.

Furthermore, the results of a follow-up univariate ANOVA tests to check the between-subject effects of the dependent variables on post-SR and post-CU, which is presented in Table 3, indicate that the only difference in mean scores to reach statistical significance, using the Bonferroni adjusted alpha level of .025, was conceptual understanding ($p < .001$) when the HACL and FCL groups were compared. An inspection of the mean scores indicate that the HACL group (M = 20.65, SD = 3.26) outperformed their counterparts in the FCL group (M = 17.13, SD = 3.40) in conceptual understanding of electric circuits. Therefore, hypothesis one was partly confirmed.

The results also showed that there was a statistically significant difference in mean scores, using the Bonferroni adjusted alpha level of .025, for both post-SR ($p < .001$) and post-CU (p < .001). An inspection of the mean scores indicate that the HD students in the HACL group (M = 8.38, SD = 1.07) outperformed their counterparts in the FCL group (M = 7.59, SD = .85) in post-SR and the HD students in the HACL group (M= 23.76, SD = 1.97) outperformed their counterparts in the FCL group (M = 20.23, SD = 1.78) in post-CU of concepts in electric circuits. Therefore, hypothesis three was also rejected.

Finally, the results showed that there was a statistically significant difference in mean scores, using the Bonferroni adjusted alpha level of .025, for both post-SR (p < .001) and post-CU (p < .001). An inspection of the mean scores indicated that the EI students in the HACL group (M = 6.48, SD = .94) outperformed their counterparts in the FCL group (M = 5.38, SD = 1.12) in post-SR and the EI students in the HACL group (M= 18.67, SD = 2.18) outperformed their counterparts in the FCL group (M = 14.76, SD = 2.17) in Post-CU of concepts in electric circuits. Therefore, hypothesis three was also rejected.

Consequently, the results of MANCOVA and ANCOVA as showed in Table 4 indicate that there was no significant interaction effect between instructional method and students' reasoning ability levels as they relate their scientific reasoning and conceptual understanding of electric circuits [$F(3,101) = .464$, $p = .63$]. This result means that the effect of instructional methods did not depend significantly on students' scientific reasoning levels in both scientific reasoning and conceptual understanding of electric circuits.

Table 1. Summary of MANOVA results of Pre- scientific reasoning (Pre-SR) and Pre-conceptual understanding (Pre-CU) of electric circuits

Level	Dependent Variables	Multivariate F	Pillai's Trace	df	p
Main Groups	Pre-SR and Pre-CU	.068	.001	2, 107	.935
HD	Pre-SR and Pre-CU	1.352	.062	2, 41	.270
EI	Pre-SR and Pre-CU	1.599	.048	2, 63	.210

Not significant, since $p > .025$

Table 2. Summary of MANOVA results of Post- scientific reasoning (Post-SR) and Post-conceptual understanding (Post-CU) of electric circuits

Level	Dependent Variables	Multivariate F	Pillai's Trace	df	p	Effect Size
Main Groups	Post-SR and CU	14.626	.221	2, 103	.001*	.22
HD	Post-SR and CU	20.693	.509	2, 40	.001*	.51
EI	Post-SR and CU	43.366	.595	2, 59	.001*	.60

*Significant, since $p < .025$.

Table 3. Summary of the follow-up analysis of variance (ANOVA) results of students on Post-SR and Post-CU of electric circuits

Comparison	Dependent variable	Univariate F	df	p	Effect size
Main Groups	Post-SR	.017	1, 104	.900	
	Post-CU	29.51	1, 104	.001*	.22
HD	Post-SR	7.18	1, 41	.011*	.15
	Post-CU	38.31	1, 41	.001*	.48
EI	Post-SR	17.95	1, 60	.001*	.23
	Post-CU	50.04	1, 60	.001*	.46

*Significant, since $p < .025$.

Table 4. Summary of MANCOVA results by the Interaction Effects and follow-up Analysis of Covariance (ANCOVA) across the two groups

MANCOVA Effect of Dependent Variables and Covariates	Multivariate F Pillai's Trace	Univariate F df=1, 99	Effect Size
Group Effect	.464 (p = .63) df = 2, 98		.009
SR		.473 (p = .49)	.005
CU		.376 (p = .54)	.004
Pre-SR	1.956 (p = .15)		.038
Pre-CU	1.152 (p = .32)		.023

5. Discussion

The first results of this study revealed that students in the HACL group outperformed their counterparts in the FCL group in conceptual understanding. The results are consistent with the argument by [28] who claimed that any form of inquiry-based teaching is effective for improving students' understanding of concepts in electric circuits. They also partly confirm the study of [32,33,34] and [35] that combination of inquiry-based simulation and real laboratory methods in cooperative learning environment leads to conceptual understanding and scientific reasoning. The outcomes could be due to the fact that students interacted freely amongst themselves during the inquiry process and during such interactions they sought explanations of difficult concepts from their more capable peers. Again, in combinational activities of simulation and real hands-on, different learners in the HACL and FCL groups benefited from the different representations which consequently increased the likelihood that students learned with the representation that best matched their needs [34].

The second results of this study showed that the HD students in the HACL group outperformed their colleagues in the FCL group in both scientific reasoning and conceptual understanding of electric circuits. These results support the findings of [3] that HD students in the heterogeneous-ability group perform better than those in the friendship-ability group in conceptual understanding but contradicts it in terms of students' scientific reasoning. The performance of HD students in the HACL group was higher because they were constantly tasked to provide explanations to their EI counterparts who needed guidance and assistance and so developed metacognition. By doing this, the HD students clarify and reorganise the concepts to make it understandable to themselves and to their EI counterparts. Such elaborative thought according to [47] helps both parties to understand the concept better. The HD student (explainer) benefits from cognitive restructuring in peer tutoring in that it might trigger understanding. Some of the HD students in the FCL group on the other hand, did not engage extensively in explaining concepts to their EI counterparts since some of the groups in FCL group were homogeneous in composition. This might have led to the significantly higher performance of the HD students in the HACL group.

Finally, the results of indicated that the EI students in the HACL group outperformed their colleagues in the FCL group in both scientific reasoning and conceptual understanding of electric circuits. These results support the findings of [3] who claim that EI students in the HACL group outperform those in the FCL group in conceptual understanding and scientific reasoning. This could be due to the fact that EI students in the HACL group had the opportunity to model the successful methods and strategies the HD counterparts used to successfully solve given problems. The hints, scaffolds and feedbacks offered by the HD students further helped to develop the EI students- ability of thinking towards HD reasoning [22]. This was demonstrated in having about 45% of EI students move to HD reasoning after being places in heterogeneous-ability groups. This confirms the notions of both Piaget and Vygotsky that cooperative learning with a more capable peers and experts results in cognitive development and intellectual growth [22,36,39]. The EI students in the FCL group on the other hand, had little benefit of peer tutoring since some of the groups were composed of homogeneous-ability groups which culminated in having only about 13% of the EI students move to HD reasoning. This was because EI students might have missed out on dialogue with HD peers who have a better understanding of the concepts and are able to elaborate and explain them more effectively to them than other EI students in their groups. Furthermore, since the average age of the students used for this study was 16.5 years old, the findings of this study disproved Piaget's model of ages and stages of cognitive development that students of age 11 years and above. Even after the various interventions and at 16.5 years old, 35% of the students used for this study were still at the concrete operational level of reasoning.

Further analysis also showed that there was no statistically significant interaction effect between instructional method and students' scientific reasoning levels with regard to scientific reasoning and conceptual understanding of electric circuits. This demonstrates that both HD and EI students benefited equally after learning through HACL or FCL grouping methods. It means that there is the high possibility that when students of the same characteristics are instructed through these methods elsewhere, there is the tendency of yielding similar results. This finding supports the study by [3] who also found that the EI and HD students benefited equally in scientific reasoning and conceptual understanding after learning through the HACL and FCL grouping methods.

6. Conclusions and Implications

It can be concluded that the use of the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping is more effective in promoting students' conceptual understanding of electric circuits than the use of the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping. These findings have filled the gap in literature which has not been able to show that the combination of inquiry-based real hands-on and computer simulation methods with heterogeneous-ability cooperative learning is very effective for promoting scientific reasoning and conceptual understanding of electric circuits. The implications of the findings of this study for improving students' scientific reasoning and conceptual understanding of electric circuits is that teachers should use the combination of inquiry-based real hands-on and computer simulation methods with heterogeneous-ability cooperative learning groupings in instructing students.

Related to the comparison of students' posttest mean score in scientific reasoning and conceptual understanding of electric circuits between both HD and EI students in HACL and FCL groups, the HD and EI students in the HACL group outperformed their counterparts in the FCL group in both scientific reasoning and conceptual understanding of electric circuits. This implies that teachers should employ heterogeneous-ability groupings during instruction and monitor the progress of hypothetical-deductive and empirical-inductive students throughout their course of study since the active engagement of students in groups promote the success of each group member. Again, Cooperative learning groups composed of students of heterogeneous abilities need to be formed after the teacher has built up adequate knowledge of student's ability levels, skills and interests before incorporating cooperative learning method into the combination of inquiry-based real hands-on laboratory and computer simulation methods.

7. Further Research

Further research needs to be conducted using the combination of inquiry-based real hands-on and computer simulation methods with heterogeneous-ability cooperative learning grouping in teaching high concepts in electric circuits such as resistivity and Kirchhoff's laws and also other concepts in physics.

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