UNIVERSITY OF CAPE COAST

EFFECTS OF COMBINING INQUIRY-BASED REAL HANDS-ON AND COMPUTER SIMULATION METHODS WITH COOPERATIVE LEARNING ON STUDENTS' LEARNING OUTCOMES IN ELECTRIC CIRCUITS

BY

GODWIN KWAME ABOAGYE

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .... Date: 16-05-2016

Name: Godwin Kwame Aboagye

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: .... Date: 16-05-2016

Name: Professor Theophilus Aquinas Ossei-Anto

Co-supervisor's Signature: .... Date: 16-05-2016

Name: Professor Joseph Ghartey Ampiah

ABSTRACT

This study 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 this study, 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 methods. The aim was to compare the two groups in terms of their scientific reasoning, conceptual understanding and changes in conception. In addition, within each group, the hypothetical-deductive and empirical-inductive students were also compared along the same three learning outcomes. A quasi-experimental method using a 2 x 2 Factorial Design was employed in the study. The results showed among other things that students in the heterogeneous-ability group outperformed their counterparts in the friendship group in conceptual understanding of electric circuits but not in scientific reasoning. It also showed that both the hypothetical-deductive and empirical-inductive students in the heterogeneous-ability group outperformed their counterparts in the friendship group in scientific reasoning and conceptual understanding. The results further showed that many more students in the heterogeneous-ability group changed their alternative conceptions more than students in the friendship group. It was recommended that senior high school teachers should employ the combination of inquiry-based real hands-on laboratory and computer simulation methods with heterogeneous-ability cooperative learning grouping when teaching to promote scientific reasoning, conceptual understanding and conceptual change in electric circuits.

KEY WORDS

Learning outcomes

Conceptual understanding

Conceptual change

Scientific reasoning

Empirical-Inductive students

Hypothetical-Deductive students

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DEDICATION

To my lovely wife, Faustina and my son, Kelvin Klint Kofi Aboagye

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CHAPTER ONE

INTRODUCTION

This study investigated the extent to which the combination of inquiry-based real hands-on and computer simulation methods would affect senior high school students' scientific reasoning, conceptual understanding, and conceptual change of electric circuits when the students are organised into heterogeneous-ability and friendship cooperative learning groupings. This study was important because research works have shown that concepts in electric circuits have proven to be difficult for students at all levels of education simply because they do not understand the behaviour of particles at the microscopic level. While various studies have recognized the importance of conceptual understanding, scientific reasoning and conceptual change of electric circuits, little attention has been paid on the effects of combining inquiry-based real hands-on and computer simulation methods with heterogeneous-ability cooperative learning grouping and friendship cooperative learning grouping in helping students achieve such learning outcomes. Based on this, the study employed the cognitive psychological theories that emphasis cognitive development and individual interaction with the environment (Piaget, 1952), social interaction (Vygotsky, 1978) and conceptual change (Posner, Strike, Hewson & Gerzog, 1982).

Background to the Study

Researchers and educators in science education community have developed curricula, methods and practices to improve science literacy by focusing on students' learning outcomes. These learning outcomes include

students' conceptual understanding, scientific reasoning and conceptual change. These are defined as the knowledge, skills, and abilities that students attain as a result of their involvement in a particular set of educational experiences (Bybee, Powell, & Trowbridge, 2008). Some studies on the developmental view have claimed that concept development is dependent on students' reasoning ability and that the ability to reason has been found to be the strongest predictor of meaningful understanding of concepts in science (Lawson, Alkhoury, Benford, Clark & Falconer, 2000; Tekkaya & Yenilmex, 2006). A number of studies have found that students who lack reasoning skills do more poorly on measures of conceptual understanding (Cavallo, 1996; Shayer & Adey, 1993).

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 (Plotnik, 2006). In accordance with the Piagetian model, though criticised and revised, formal thought begins to develop at the age of 11 or 12 years and reaches an equilibrium state at around age 15 and 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 (Fah, 2009; Remigio, Yangco, & Espinosa, 2014) and also as many as 50% of students in freshmen-level college biology do not engage in higher order scientific reasoning (Lawson, 1995). The model asserts that concrete reasoners are unable to develop sound understanding of abstract concepts. While concrete operational students are able to understand only concrete concepts, formal operation students are able to understand both concrete and formal concepts. Concrete and formal operational thoughts were renamed by Lawson (1995) as empirical-inductive [EI] and hypothetical-

deductive [HD] thoughts, respectively. The EI student is a low-ability student whose reasoning is at the concrete operational level while the HD student is a high-ability student whose reasoning is at the formal operational level as specified by Piaget (1952). The EI students' reasoning patterns include conservation and serial ordering while the HD students' reasoning patterns include proportional reasoning, identification and control of variables, probabilistic reasoning, combinational reasoning and correlational reasoning (see Lawson, 1995; Kuhn, 2010; Remigio et al., 2014).

The difficulties that students have with formal concepts relate to their inability to apply scientific reasoning skills that are necessary for explaining scientific concepts (Tekkaya & Yenilmex, 2006). Electric circuits, for example, is one of the topics that has been found to be difficult for students at all levels of education to understand since it requires the understanding of the behaviour of particles at the microscopic level (Chiu, 2001; Hart, 2008; McDermott & Shaffer, 1992; Reiner, Slotta, Chi, & Resnick, 2000). The central concepts, such as voltage, current and resistance, are difficult, complex and abstract by nature and so require the application of HD thought to aid understanding (Carlton, 1999; Chiu, 2001; Pfister, 2004).

We have electric lamps, electric cookers, electric clocks, and computers at our various homes. We also know that cars, trains, and planes require electricity to function. It is, therefore, not surprising that students enter science classrooms with a wide range of ideas and beliefs about electricity that they have acquired from their everyday experiences (Glauert, 2009; Solomonidou & Kakana, 2000). Students use these internal representations (i.e., mental models) to predict the behaviour of electricity and to explain electric circuits (Chi, 2008). Unfortunately, many of the students' intuitive ideas that constitute their mental models are incomplete and conflict with scientific explanations of electric circuits (Chiu & Lin, 2005; Lee & Law, 2001; Sencar & Eryilmaz, 2004). Researchers use different names for these scientifically inconsistent ideas, namely 'preconceptions', 'misconceptions', 'alternative conceptions', 'intuitive conceptions', 'conceptual misunderstanding', 'spontaneous ideas', 'intuitive law or spontaneous reasoning', 'conceptual framework', 'students' unscientific beliefs or students' conceptual categories' and 'spontaneous models' (Aguirre, 1998; Eryilmaz, 2002; Sherin, 2006; Marin, Benarroch, & Jiménez, 2000; Tsai & Chou, 2002). In this study, the term 'alternative conceptions' is preferred and it refers to students' conceptions that are deemed to be in conflict or at odds with modern scientifically accepted explanations or theories in science.

Earlier studies conducted have dealt with identifying students' alternative conceptions related to concepts in electric circuits (Baser & Durmus, 2010). Some research works (Lee & Law, 2001; McDermott & Shaffer, 1992) conducted to determine primary school, high school and university students' ideas about simple electric circuits have identified the following alternative conceptions about simple electric circuits: (1) Current get consumed by its closed circuits components (like bulb and resistors), and therefore, diminishes when it returns to the battery. (2) The current comes from both polarities of a battery and when they collide on the bulb, the bulb gives light (Current as collisions of charges). (3) Only one wire is needed to connect battery and bulb and the second connection to the other polar of the battery is not necessary for giving off light (One polar current model). (4) Battery is seen as stationary source of current. (5) The more dry cells in a circuit, the more brightness of the bulb irrespective of the circuit

configuration. (6) Using the following terms interchangeably: current, energy, and potential difference. (7) When bulbs are connected to each other in parallel, the current splits equally to the bulbs irrespective of the value of the bulb's resistance. Though these general alternative conceptions have been identified, there are however, alternative conceptions which are peculiar to certain cultural settings, countries, level of education and different age groups (Baser, 2006a). Thus, research needs to be conducted in such contexts to determine students' alternative conceptions in order to help teachers find solutions to such alternative conceptions.

Later studies (Carlsen & Andre, 1992; Chiu & Lin, 2005; Tsai, 2003) conducted attempt to change these alternative conceptions and promote students' understanding of concepts in electric circuits using different teaching strategies despite the fact that changing students' alternative conceptions is not an easy task. This is because these conceptions are very stable, pervasive and well embedded in students' cognitive domains which makes them often resistant to change through classroom instruction (Sungur, Tekkaya, & Geban, 2001). For example, Tsai (2003) investigated the effectiveness of using conflict maps on refining high school students' alternative conceptions about simple series electric circuits and concluded that conflict maps have positive effect in remediating students' alternative conceptions. Chiu and Lin (2005) used analogies for promoting conceptual change and showed that the use of analogies helped students refine their alternative conceptions concerning electricity. Conceptual change texts can also be used to change students' alternative conceptions related to electricity (Carlsen & Andre, 1992).

One other way researchers and teachers have addressed the problems of

scientific reasoning, conceptual understanding and conceptual change is through the development and use of inquiry-based methods (National Research Council [NRC], 1996). One of the inquiry-based models that have gained recognition in promoting meaningful learning and logical thinking (Bybee, 2004; Lawson, 2001; Musheno & Lawson, 1999) is the 3-E inquiry-based learning cycle model (i.e., exploration, explanation and expansion phases). It is a model which has proven effective at helping students construct concepts and conceptual systems as well as develop more effective reasoning patterns (Lawson, 2001; Türkmen, 2006). It allows students to reveal their beliefs and conceptions, to test their beliefs, to develop more adequate conceptions and more effective for learning complex and non-intuitive concepts simply because it follows Piaget's four stages of mental functioning – assimilation [exploration phase], disequilibrium [exploration phase], accommodation [explanation phase] and reorganization [expansion phase] (Aksela, 2005). The inquiry-based learning activities which will be used in this study will follow the 3-E inquiry-based learning cycle model.

Research works have indicated that inquiry-based learning conducted through real hands-on laboratory method and computer simulation method fosters scientific reasoning, performance and conceptual change by engaging students in exploring the given tasks that are expected to lead them to state hypothesis, carry out experiments, create models and theories, and evaluate them as scientists do (Finkelstein et al., 2005; Zacharia, 2007). In a computer simulation method, students are engaged in active inquiry instead of merely witnessing something being presented (de Jong, 2006; Wieman, Adams, & Perkins, 2008). The students can set up different virtual circuits, change circuit variables (e.g., voltage and resistance) one at a time and observe the outcomes of their actions and reasoning

(e.g., change in bulb brightness) (de Jong, 2006). This allows the students to become better aware of the limitations of their initial reasoning (the output of the simulation may be in conflict with their expectations) and discover the properties of the scientific model embedded in the simulation (e.g., the electric circuit is a closed system in which all components interact; Ohm's law; total resistance in parallel and series circuits) (de Jong, 2006; Lehtinen & Rui, 1996; Wieman, Perkins & Adams, 2008). A distinctive feature of computer-simulations is that the embedded model(s) often highlights the elements that are important for theoretical understanding (e.g., interdependence between current, voltage, and resistance) and excludes (or hides) the elements that are 'irrelevant' or potentially misleading (e.g., poor connections, worn batteries, tangled wires, colour of wires, or even broken wires or bulbs) (Finkelstein et al., 2005; Goldstone & Son, 2005). On the other hand, in comparison with real hands-on laboratory circuits, a simulation can make the functioning of electric circuits more transparent; it can model circuits on various levels of abstraction (e.g., a circuit in schematic format and the mimicking of real bulbs and wires) and visualize processes that are invisible in natural systems (Finkelstein et al., 2005; Goldstone & Son, 2005). As an example of a naturally "hidden" process, the existence of current cannot be observed in real circuits, but an electricity simulation can easily show whether or not there is a flow inside a circuit, the path of that flow, and possibly even its magnitude. Such lack of adequate information plays a role in many alternative conceptions about electric circuits and makes it more difficult to learn the scientifically correct models (McDermott & Shaffer, 1992; Ronen & Eliahu, 2000). Finkelstein et al. (2005), for instance, examined the effects of substituting a computer-simulation for real circuits in the learning of the basics of direct current (DC) circuits in a university physics course. They found that the students using the simulation outperformed the students using the real circuits both on a conceptual knowledge test and in the coordinated tasks of assembling a real circuit and describing how it worked. Both of these experimental groups outperformed a control group that consisted of students who participated in a calculus-based physics course. The control group attended lectures on basic DC circuits and completed homework, but did not use the simulation or real circuits. Additional classroom observations further revealed that the students using real equipment sometimes had difficulties in constructing closed circuits and were 'misled' by the surface features of the circuits. Such problems did not occur in the simulation environment.

Despite the popularity and potential advantages that computer simulation method might have over real hands-on laboratory method, some researchers claim the use of computer simulations in some science domains may deprive students of experiences that involve concrete or hands-on manipulations of physical materials which are essential for learning on those domains (Clark, 1994). One of the primary reasons that some researchers and educators discriminate against computer simulations is because they consider that when using computer simulations, they are asking their students to learn in a fundamentally different way than scientists originally work on the corresponding issues (Steinberg, 2000). On the other hand, other researchers claim it is manipulation rather than physicality that may be the important component of instructions (Resnick, 1998). Based on these arguments between the use of computer simulations and real hands-on laboratory activities and the potential advantages and disadvantages of both methods, some researchers have started to investigate the potential benefits

of combining rather than contrasting the two.

For instance, in a study by Jaakkola and Nurmi (2008), fourth and fifth grade students in one Finnish elementary school solved circuit assignments in three different learning conditions - a computer simulation (only simulation), a hands-on laboratory exercise (only real circuits) and a simulation-laboratory combination (simulation and real circuits in parallel). The results showed that the development of conceptual knowledge was most notable in the combination condition. Students in the simulation condition also made clear progress during the intervention, but their understanding did not reach the level of the combination condition in the posttest. The progress was most modest in the laboratory condition where the students' conceptual understanding remained low after the intervention. In the other study, Zacharia (2007), in investigating the value of combining real laboratory with virtual laboratory with respect to changes in students' conceptual understanding of electric circuits found that virtual laboratory combined with real laboratory experimentation could promote university students' conceptual understanding more than real laboratory experimentation alone. Also, Zacharia, Olympiou and Papaevripidou (2008), showed that experimenting with the combination of real laboratory and virtual laboratory enhanced university students' conceptual understanding of heat and temperature more than experimenting with real laboratory alone. In a study by Farrokhnia and Esmailpour (2010), in investigating the comparative value of performing experiments by physical, virtual and comprehensive (combination of virtual and physical) methods with respect to changes in university students' conceptual understanding of DC electric circuits and their skills found that students in the comprehensive group outperformed those in both virtual only and real only groups but there was no significant difference in understanding between the students in the virtual and real groups. However, in all these studies, time as a factor was not controlled which in effect gave the combinational group more advantage over the simulation only and real laboratory only groups. There is therefore the need for a study to be conducted where all the groups will be given equal time on all tasks. Again, though the combination of real hands-on laboratory activities and computer simulations have proven effective for promoting conceptual understanding of concepts in electric circuits, it appears research has not yet shown how the combinational activities can be done taking into account the large class sizes (Yelkpieri, Namale, Esia-Donkoh, & Ofosu-Dwamena, 2012), the limited apparatus and computers in our schools especially in Ghana (Aidoo, Johnson, & Aboagye, 2013).

Research works have shown that cooperative learning has the potential of solving these problems since cooperative learning strategies serves as a medium or an environment for other teaching methods to be used to achieve maximum educational goals (Thanh & Gillies, 2010). Cooperative learning is a structured and systematic instructional strategy in which students in teams work together towards a common goal (Cooper & Mueck, 1990). According to Cooper and Mueck, the learning activities of cooperative learning include: (i) negotiating a common goal with team members, (ii) being responsible for the learning of individual members as well as that of the team members, (iii) assigning complementary roles and tasks to individuals within each group, and (iv) cultivating social skills for effective cooperative learning. Many studies of cooperative learning conducted with diverse subject areas and a wide range of tasks provide evidence that cooperative learning is an effective learning and teaching approach (Liu & Cheng, 2007). Previous studies also show that cooperative learning benefits students in terms of achievement, motivation, critical thinking, meta-cognitive thought, job satisfaction, and social skills (Johnson & Johnson, 2004). Previous studies also pointed out some important factors that may affect the effectiveness of cooperative learning, including positive interdependence, individual and group accountability, promotive interaction, appropriate use of social skill, resources, and group processing (Cohen, 1994; Johnson & Johnson, 2004). In sum, there is a solid stepping-stone for teachers to apply cooperative learning in most classroom learning activities.

Although much of the evidence regarding cooperative learning is positive (Hagen, 2000; Lord, 2001), research in education questions the efficacy of cooperative learning based on the type of group composition (Ryan, Bordoloi, & Harrison, 2000; Wehrs, 2002). These findings, coupled with the potential drawbacks and complexities of implementation associated with cooperative learning, raise additional questions regarding the use of cooperative learning techniques in science courses (Joyce, 1999). The problem the teacher faces most is how to group the students into teams. One especially problematic question many teachers face is, whether students should be allowed to choose their own group mates or grouping should be done? This pressure stems from the notion common in childhood and adolescence that one works better with friends, rather than the reality of adult life in which one is not necessarily friends with co-workers (Cohen, 1994). When teachers grapple with this question, they are confronted with a decisive and determining factor of successful cooperative learning and the complications that may arise in classroom settings. In a casebook for teachers in the UK about group work in the classroom, 38% of the cases were concerned with difficulties teachers face in creating groups (Mitchell, Reilly, Bramwell, Solnosky, & Lilly, 2004).

Research has shown that there are three different ways students can be placed into groups and these include homogeneous (ability) grouping, heterogeneous grouping and friendship grouping (Morgan & Keitz, 2010; Poole, 2008; van der Laan Smith & Spindle, 2007). According to Poole (2008), homogeneous grouping involves grouping students according to their intellectual abilities which makes teachers put high ability [HD] students, medium ability students and low ability [EI] students into separate groups. Heterogeneous grouping involves grouping students into mixed ability groups that is combining high, medium and low ability students in a single group. Friendship grouping on the other hand involves allowing students to choose their own group mates (who are friends) to work with without the influence of the teacher.

Research is replete with the fact that homogeneous groupings have the potential to improve students' achievements and reasoning skills (see for instance, Adodo & Agbayewa, 2011; Emily, Robert & Michael, 2003; Slavin, 1995). However, it appears the drawbacks of homogeneous groupings outweigh their benefits. The study by Emily, Robert and Michael (2003) revealed that if students are grouped homogeneously, there is the fear that EI students will be deprived of opportunities to learn and be unmotivated to learn because of peer, personal and teachers' expectations of poor performance. Harsher critics of homogeneous grouping say it is just another form of racial segregation; for when students are divided on the bases of ability grouping, they are also divided by race and economics (Adodo & Agbayewa, 2011). However, Lou, Abrami, Poulsen, Chambers and d'Apollonia (1996) claim that it is unethical to retard the

achievement of HD students by assigning them to heterogeneous group class settings where they might spend their time instructing their EI counterparts rather than learning information they did not already know. Contrary to the views of Lou et al., Vygotsky (1978) believes that social interaction among students and their peers enables them to extend their knowledge.

According to Vygotsky (1978), there is a hypothetical region where learning and development best take place. He identifies this region as the zone of proximal development. This zone is defined as the distance between what an individual can accomplish during independent problem-solving and what can be accomplished with the help of an adult or a more capable member of a group. With cooperation, direction, or help, from a more skilled partner, as in an instructor or a more capable peer (i.e., HD student), the individual is better able to solve more difficult tasks than he or she could independently. Research indicates that cooperative learning groups seem to help all students because the best students get to 'impart' their knowledge to others and the weaker students receive peer coaching (Heller, Keith & Anderson, 1992). This is supported by Hooper and Hannafin (1991) whose study gave evidence that EI students improved their performance more than 50% when grouped heterogeneously.

While homogeneous and heterogeneous groupings have gained popularity in the western countries like the USA and UK, friendship grouping is also gaining popularity in the Asian countries due to difference in cultural settings, values and beliefs of learning (Thanh & Gillies, 2010). In the context of Asian countries, homogeneous and heterogeneous groupings methods may not work because Asians pay special attention to the importance of personal relationship and consider affection between co-workers as a crucial factor in determining the

success of a group (Thanh & Gillies, 2010). For Asian collectivists, the ideal grouping method would be based on affection and personal relationships and so they advocate for friendship groupings to be adopted in their classrooms. This seems to be the method adopted by most teachers in Ghana due to our belief in democracy and freedom of association.

In fact, a number of studies on cooperative learning have found that friendship groups tend to have superior learning outcomes in comparison with random or ability groupings (Chauvet & Blatchford, 1993; Fraysse, 1994; Kutnick, Blatchford, & Baines, 2005; Zajac & Hartup, 1997). Despite the successes of friendship grouping, the problems of group composition often arise. The danger here may be that the members of the friendship group may not be heterogeneous but rather homogeneous which may not help in certain areas where all the group members operate at the empirical inductive mode (Abdullah & Shariff, 2008). The students in the friendship group may all be either hypothetical-deductive students or empirical-inductive students and in few cases mixed. When this happens, the criticisms against homogeneity may come to play. Based on this, it is likely or it appears students in heterogeneous group will perform better on a given task than students in friendship group in instances where the group composition is made up of only low ability or empirical inductive students.

Cooperative learning strategies serves as a medium or an environment for other teaching methods to be used to achieve maximum educational goals (Thanh & Gillies, 2010). Consequently, since the use of cooperative learning through either heterogeneous groupings and friendship groupings have been found to be successful in helping students develop concepts and the combination of real

hands-on laboratory activities and computer simulations activities have also been used successfully to promote students' conceptual understanding and scientific reasoning at various levels of education, it is important to conduct a study to investigate the effects of combining inquiry-based real hands-on method and inquiry-based computer simulation method with cooperative learning environments (i.e., friendship and heterogeneous) to see whether it will help students develop scientific reasoning and conceptual understanding of electric circuits effectively and also to aid conceptual change.

Although Abdullah and Shariff (2008) measured the effect of computer simulations with cooperative learning on students' understanding of gas laws with success, there appear to be very few research studies, if any, that have shown how cooperative learning can be incorporated into the combination of real hands-on and computer simulation methods in investigating their effectiveness in promoting senior high school students' scientific reasoning, conceptual understanding and changes in conceptions of electric circuits. Again, since the context of a study can also influence the results of a study, this study therefore seeks to test the effect of placing students in heterogeneous-ability cooperative learning [HACL] grouping and friendship cooperative learning [FCL] grouping as used in Abdullah and Shariff (2008) and using the combination of inquiry-based real hands-on and computer simulation methods, to investigate how much, if any, these grouping methods facilitate students' scientific reasoning, students' conceptual understanding and students' conceptual change of electric circuits.

Statement of the Problem

Electric circuit – a topic in direct current electricity – is one of the topics in physics studied and taught at pre-tertiary schools and tertiary institutions in Ghana. Sound development of concepts in electric circuits forms the basis or prerequisite for understanding other higher topics like electrical energy, capacitance, alternating current theory, magnetic fields, electromagnetic induction, electronics, photoelectricity as well as many other topics in physics. This makes electric circuit a critical topic which needs to be taught and developed adequately in order to improve students' performance in physics. However, students have difficulties when they are required to apply concepts and principles of electric circuits (The West African Examination Council [WAEC], 2000, 2001, 2002, 2006, 2011, 2012 & 2013). Some of the difficulties students face in electric circuit identified were: their inability to draw electric circuits and interpret them (WAEC, 2002); poorly conducted experiment to determine the resistivity of a wire (WAEC, 2001 & 2002); students inability to apply Kirchhoff's law to solve simple questions (WAEC, 2000 & 2012); most students could not establish that resistance is inversely proportional to current (WAEC, 2011); majority of the candidates failed to recognise the relationship between resistance and the balance length on a metre bridge (WAEC, 2006 & 2013). 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.

Researchers (Aboagye, Ossei-Anto & Johnson, 20011; Carlsen & Andre, 1992; Chiu & Lin, 2005; Tsai, 2003) have made attempts to use 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 (Ates, 2005; Baser, 2006a; Baser, 2006b; Clark, 1994; de Jong, 2006; Scheckler, 2003; Triona & Klahr, 2003). Proponents of real hands-on laboratory method have emphasised typically the importance of authentic experiences to foster student learning (Ates, 2005; Clark, 1994; Scheckler, 2003). Meanwhile, the proponents 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 (Baser, 2006a; Baser, 2006b; de Jong, 2006; Triona & Klahr, 2003). Even though computer simulations alone have been used to promote scientific reasoning and conceptual understanding of electric circuits in other developed countries (Abdullah & Shariff, 2008; Baser, 2006a; Baser, 2006b), it may not always be the case when it comes to most developing countries like Ghana. This is because not all the schools in Ghana have access to electricity, computer laboratories and simulation software.

Since research findings are always affected by the context of the study (Johns, 2006), it is critical to consider the educational system in Ghana 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 Ghana, students are made to perform real hands-on electric circuit practicals during the final examinations at WASSCE 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 senior 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 (Farrokhnia & Esmailpour, 2010; Jaakkola & Nurmi, 2008; Jaakkola, Nurmi, & Veermans, 2011; Zacharia, 2007).

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 that gap.

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 educational goals such as conceptual understanding, conceptual change and scientific reasoning (Kutnick, Blatchford & Baines, 2005; Thanh & Gillies, 2010). This is because in cooperative learning, a less skillful individual (EI student) is better able to develop a more complex level of understanding and reasoning through collaboration with a more capable peer (HD student) than he/she could do independently (Abdullah & Shariff, 2008; Lawson, 2001). Although cooperative learning has been used successfully in achieving educational goals, research in education still questions its efficacy in terms of the type of group composition. Some research findings have advocated for the use of friendship and heterogeneous-ability group compositions based on their enormous strengths. Though various researches have shown the importance of friendship and heterogeneous-ability groupings in promoting students' conceptual understanding, little attention has been paid to their effects in helping EI students move toward HD thought. It also appears very few studies, if any, which 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 students' conceptual understanding of electric circuits. Again, while various studies have recognized the importance of conceptual change, little attention has been paid on the empirical study of the effects of combining inquiry-based real hands-on and computer simulation methods with heterogeneous-ability cooperative learning grouping and friendship cooperative learning grouping in helping students change their conceptions. Hence this current study.

Purpose of the Study

The overarching purpose of this study was to ascertain the extent to which the combination of inquiry-based real hands-on and computer simulation methods would affect senior high school students' scientific reasoning, conceptual understanding, and conceptual change 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) as mentioned in Abdullah and Shariff (2008). From this, six sub-purposes were formulated to guide the study.

Firstly, the study investigated the effect of the combination of inquiry-based real hands-on and computer simulation methods on students' conceptual understanding of electric circuits and scientific reasoning in the HACL and FCL groupings. Secondly, students in each of the two groupings were compared on the basis of the changes in their conceptions.

In addition, students in the aforementioned cooperative learning groupings were subdivided into two groups each (i.e., HD and EI students). From this, four purposes (i.e., the third to six) of the study emerged. The third purpose involved comparing the HD students in each of the two groupings on their conceptual understanding and scientific reasoning after they have been taught using the combination of inquiry-based real hands-on and computer simulation methods, while a similar comparison of the EI students in the two groups constituted the fourth purpose. The interactions between the instructional methods and students' scientific reasoning levels in scientific reasoning and conceptual understanding were also investigated. Finally, similar comparisons of the HD students in both groups, as well as the EI students in the two groups on

the changes in conceptions constituted the fifth and sixth purposes of the study.

Hypotheses

Based on evidence in related literature, the following six hypotheses guided the study. The hypotheses were tested at .05 level of significance.

1. **H_{01}**: There is no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between senior high school 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.

   H_{A1}: Senior high school students taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping will perform significantly higher in (a) scientific reasoning, and (b) conceptual understanding of electric circuits than those taught using the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping.

2. **H_{02}**: There is no statistically significant difference in the degree of changes in conception in electric circuits between senior high school 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.

H_{A2}: Senior high school students taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping will change their conceptions in electric circuits better than those taught using the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping.

3. H_{03}: There is no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between HD senior high school 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.

   H_{A3}: HD senior high school students taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping will perform significantly higher in (a) scientific reasoning, and (b) conceptual understanding of electric circuits than their HD counterparts taught using the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping.

4. H_{04}: There is no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between EI senior high school 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.

   H_{A4}: EI senior high school students taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping will perform significantly higher in (a) scientific reasoning, and (b)

conceptual understanding of electric circuits than their EI counterparts taught using the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping.

5. **H_{05}**: There is no statistically significant difference in the degree of changes in conception in electric circuits between senior high school HD 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.

   H_{A5}: HD senior high school students taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping will change their conceptions in electric circuits better than their HD counterparts taught using the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping.

6. **H_{06}**: There is no statistically significant difference in the degree of changes in conception in electric circuits between senior high school EI 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.

   H_{A6}: EI senior high school students taught using the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping will change their conceptions in electric circuits better than their EI counterparts taught using the combination of inquiry-based real hands-on and

computer simulation methods with FCL grouping.

Significance of the Study

Firstly, the various inquiry-based teaching activities and the various instruments that were developed in this study could be useful to improve upon the teaching and testing of students' knowledge on concepts in electric circuits. Secondly, the outcome of this study could show physics teachers how the inquiry teaching activities are carried out in the classrooms on specific concepts in direct current electricity. Thirdly, the outcome of this study could reveal students' alternative conception on concepts in electric circuits peculiar to senior high school students which could help teachers, curriculum developers and course programme writers in developing lessons and syllabi. Finally, the results of this study would contribute knowledge and add to existing literature to aid further research in science education.

Delimitations

The study focused only on selected concepts in electric circuits as reflected in the senior high school [SHS] Form 2 syllabus for physics. Since electric circuit is a broad topic, all its content cannot be covered in a single study and therefore concepts covered were electric current, electric voltage, electromotive force, electric resistance, Ohm's law, parallel and series connections of resistors, bulbs and dry cells and the combination of both parallel and series configuration of bulbs, dry cells and resistors. The study did not cover concepts such as types of cells, resistivity, Kirchhoff's laws and experiments using potentiometer and Metre Bridge. The study also focused only on SHS Form

2 students offering physics, chemistry, biology and mathematics as elective in the

Cape Coast Metropolis.

Limitations

The study could not control extraneous variables such as age, maturation, experience and previous learning which may have influenced students understanding of concepts in electric circuits and so may lack internal validity. Again, not all students were present for all the lessons designed which could also affect the outcome of the study.

Organisation of the Study

Excluding the 'Introduction' chapter, there are four other chapters made up of Review of Related Literature (Chapter Two), Methodology (Chapter Three), Results and Discussion (Chapter Four) and Summary, Conclusions and Recommendations (Chapter Five). The review of related literature chapter takes a critical look at the relevant literature that is related to this research. These comprised inquiry-based science learning, combination of real hands-on and computer simulation methods, cooperative learning, scientific reasoning, theoretical framework, empirical studies on the comparison of computer simulation method and real hands-on method and the combination of the two methods, and studies on students' alternative conceptions in electric circuits and changes in conception.

Chapter Three discusses the research methodology of the study. It describes the type of study and design in detail, and the rationale for the design. Issues relating to population, sample and sampling procedure, instruments, data collection procedure, and data analysis are also discussed in detail.

In Chapter Four, the results of the study are presented and discussed

according to the hypotheses raised. Literature supporting the findings are also provided to support the hypotheses stated. In Chapter Five, an overview of the research problem and methodology are given. A summary of the key findings and their interpretations are also provided. Conclusions and implications relating to the findings are also discussed. In addition, recommendations are made and the issues unearthed for possible future research are presented.

Definition of Terms

Conception: Is being able to form and articulate the major concepts of electric circuits in the scientific manner.

Conceptual change: Is the degree to which students change their alternative conception for the scientifically accepted conceptions.

Conceptual understanding: Having made conceptual change is no guarantee that students can apply the scientific concepts they have in solving problems in novel situations and make correct inferences. Consequently, the ability to apply the concepts in electric circuits in novel situations to solve problems, make judgements and inferences and so on is referred to as conceptual understanding.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews literature related to the study. The review draws out some theoretical issues on inquiry-based learning, combination of inquiry-based real hands-on laboratory and computer simulation methods, cooperative learning, scientific reasoning and conceptual change, and out of which the theoretical framework for the study was derived. Finally, empirical studies were also reviewed.

Inquiry-Based Science Learning

It is difficult to exactly trace the first appearance of inquiry-based teaching and learning, but research (NRC, 1996) indicates that it was born out of the work of John Dewey, Jean Piaget, Lev Vygotsky, Jerome Bruner and David Ausubel. These thinking processes transformed into the philosophy of learning known as constructivism (Cakir, 2008). Constructivist approaches emphasise that knowledge is constructed by an individual through active thinking, defined as selective attention, organisation of information, and integration with or replacement of existing knowledge; and that social interaction is necessary to create shared meaning (Cakir, 2008; Fay, Grove, Towns & Bretz, 2007; Mayer, 2004). Therefore, an individual needs to be actively engaged both behaviorally and mentally in the learning process for learning to take place. Constructivist pedagogies are student-centered and student-directed; they work by reflectively connecting new learning to existing cognitive structures; they are dependent upon discursive, socialised instructional environments; and they are dependent upon collaborative and cooperative learning between students and with teachers and other disciplinary masters (Dewey, 1997; Prince & Felder, 2006). Activities that engage students in scientific inquiry facilitate their construction of knowledge (Fay et al., 2007). This means all forms of inquiry-based learning can be termed as constructivist methods of learning.

Since the late 1980s, a shift toward inquiry-based learning has been one of the new approaches advocated for science education. Students at all levels and in every science domain should have an opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry (NRC, 1996). The call for inquiry learning by science educators is based on the conviction that science learning is more than the memorisation of scientific facts and information, but rather is about understanding and applying scientific concepts and methods (Bell, Urhahne, Schanze & Ploetzner, 2010). Albeit the importance of inquiry learning is widely recognised, it is difficult, if not impossible, to give a commonly accepted definition (Cuevas, Lee, Hart, & Deaktor, 2005). To solve the problem of finding an appropriate definition for inquiry, the NRC (1996) proposed a definition which captures the essence of inquiry:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires

identification of assumptions, use of critical and logical thinking, and

consideration of alternative explanations (p. 23)

Scientists use inquiry to develop understanding of the natural and man-made world, because it leads to theories and ideas that explain observed events and phenomena. Inquiry, in fact, consists of varying degrees of approaches ranging from a more traditional approach, to a more open inductive approach where students generate their own experiments. The NRC (2000) determined that inquiry contains five essential characteristics: 1. Learners are engaged by scientifically oriented questions. 2. Learners have the ability to determine what data allows them to develop and evaluate scientific explanations. 3. The students will have the ability to formulate their own explanations from the evidence they have obtained. 4. Students can expand upon their findings and relate those findings to similar situations. 5. The learner will then be able to communicate their experimental findings to others in class via small group work, presentations to the entire class, or written laboratory reports.

Through reflecting on the processes during inquiry-based learning activities, students are given opportunities to explore and understand both the cognitive and affective domains of 'learning to learn' (Hacker, 1999). Understanding and dealing with thoughts and feelings makes inquiry-based learning a powerful learning experience for students and teachers. Studies investigating the implementation of inquiry-based science education, inquiry-based information literacy programs and other inquiry-based educational innovations have resulted in guidelines for building a culture of inquiry (Fullan, 1991). The National Science Foundation (NSF) has put out a call for teachers to educate students in the ability to formulate useable questions, plan appropriate experiments, conduct observations, interpret, and analyse data, draw conclusions,

communicate their results, as well as being able to coordinate and implement a full investigation (NRC, 2000; Thomas, 2005). Toward this end, there has been a resurgence of interest and research in the inquiry approach to science. Inquiry in general involves students obtaining and constructing their own knowledge rather than receiving the information from a didactic lecture or a cookbook laboratory (Thomas, 2005).

Teachers play varied roles in supporting students' development of inquiry skills. These roles include modeller, guide, diagnostician, facilitator, mentor, and collaborator, which indicate a varied amount of structure and scaffolding teachers build into an activity (Wu & Hsieh, 2006; Crawford, 2000). Well-designed, inquiry-type laboratory activities, in particular, can provide learning opportunities to help students build higher-level learning skills and meta-cognitive abilities (Hofstein, 2004). Students are challenged to ask appropriate questions by finding and synthesising information, monitoring scientific information, designing investigations, and drawing conclusions (Krajcik, Mamlok & Hug, 2001). Students participating in inquiry are often more active and initiate more ideas than they do within ordinary laboratory activities. Students taught concepts have made significant progress in formulating hypotheses, making proper assumptions, designing and executing investigations, understanding variables, recording data, and synthesising new knowledge (Lechtanski, 2000). In particular, technology-supported inquiry activities offer the opportunity to increase students' experience with authentic activities and achieve deeper content understanding (Edelson, 2001). Student curiosity is at the center of inquiry. An inquiry-based approach encourages curiosity and openness, and fosters a stronger sense of responsibility and satisfaction among students (Lechtanski, 2000).

There is, however, no single method of inquiry teaching (NRC, 2000). There are various pedagogical models for inquiry to support meaningful learning, for example, structured inquiry, guided inquiry, open inquiry, and confirmatory inquiry. Inquiry-based learning approaches can vary according to the extent of direction provided by a teacher and the extent of independence given to students (DeBoer, 2004). Aksela (2005, p. 66) defined four levels of inquiry-based teaching:

> (a) *Confirmation* inquiry *activities which* require students to verify concepts through a given procedure. (b) *Structured-inquiry activities which* provide students with a guiding question and procedure to follow. An example of a structured inquiry learning approach is the Inquiry-based Learning Cycle Model (used in this study), based on Piaget's theory of cognitive learning (Abdi, 2014). (c) *Guided inquiry activities which* provide students with a guiding question and suggested materials; however, students design and direct the investigation. (d) *Open-inquiry activities which* require students to generate their own research questions and design their own investigations.

Inquiry learning often incorporates an element of collaboration which means the engagement of participants in a common endeavour (Dillenbourg, 1999). There are a number of arguments why collaboration among learners is effective for inquiry-based learning. According to socio-constructivist learning theories (Duit & Treagust, 1998), knowledge emerges by collaborative search of problem solutions in communities with distributed information among its

members. Piaget pointed at the importance of social interaction for the emergence of cognitive conflicts. These socio-cognitive conflicts form the basis of considerable cognitive developments and performances and might appear in inquiry learning processes as well (Lehtinen, 2003). Finally, Vygotsky's idea of the zone of proximal development has been helpful for understanding the effects of collaborative experiences; collaborating peers offer zones of proximal development to each other (Abdi, 2014). Crook (1991) further developed the idea to capture the whole of the context formed by classmates, the teacher, and technical media in which learning takes place. In the meantime, theoretical reflections and empirical studies have demonstrated the potential of student collaboration; the role computer tools can play to support it as well as conditions for success (Pilkington, 2004; Pilkington & Walker, 2003).

There are several arguments based on theory and empirical studies about how computerised tools can support student inquiry. Two very general reasons for the use of computer tools for inquiry have been described in the research literature (Edelson, Gordin, & Pea 1999; Lehtinen, 2003; van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005). First, computer tools help students to focus on higher learning processes which are characteristics for inquiry. Computers support learners in planning investigations or constructing knowledge by assuming large parts of routine processes like calculating, acquiring, sorting, or visualising data, retrieving and saving information. Second, the computer system can be controlled by the learners themselves. They can access information and hints via the interface on their own initiative and do not necessarily have to rely on the teacher. Self-regulated learning with all its positive effects on

motivation can be realised.

Inquiry-based learning cycle model

The inquiry-based learning cycle model called simply learning cycle, introduced by Karplus and Thier for the Science Curriculum Improvement Study (SCIS), has evolved into one of the most important teaching approaches in science education (Türkmen, 2006). Learning cycle can promote meaningful learning and logical thinking (Bybee, 2004; Lawson, 2001; Musheno & Lawson, 1999). The learning cycle model has proven effective at helping students construct concepts and conceptual systems as well as develop more effective reasoning patterns, primarily because it allows students to use *if/then/therefore* reasoning to test their own ideas and to participate in knowledge construction processes (Lawson, 2001). Research shows that the learning cycle enables students to develop better conceptual understanding, improve their thinking skills, and develop positive attitudes towards science and science instruction (Lawson, 2001). The learning cycle model allows students to reveal their beliefs and conceptions and to test their beliefs, and to develop more adequate conceptions (Aksela, 2005). It is suitable, in particular, when the development of thinking skills is a main goal (Türkmen, 2006). It is more effective in learning complex and non-intuitive concepts (Aksela, 2005). In the light of these descriptions, the learning cycle is an inquiry-based learning and its "goal is to enhance learning and provide students with more authentic science experiences that imitate those real scientists and are in accordance with the nature of science" (Türkmen, 2006, p.73).

Various models of learning cycles are reported in the literature. The

original Learning Cycle (the 3-E learning cycle model) consists basically of three essential phases of *Exploration, Explanation* (Term introduction) and *Expansion* (Concept Application) for the development of reasoning skills, conceptual understanding and change in conceptions (Türkmen, 2006). A *language-oriented learning cycle* (Glasson & Lalik, 1993) is based on social constructivism theory in which language can be used to stimulate cognitive activity. The *MORE learning cycle* (Tien, Rickey & Stacy, 1999) - Model, Observe, Reflect, and Explain (MORE) - emphasises how to think through the inquiry process rather than focusing on how to perform laboratory procedures and algorithmic calculations. The *prediction/discussion-based learning cycle* (Lavoie, 1999), when compared to conventional learning-cycle instruction, produced significant gains in process skills, logical thinking skills, science concepts, and scientific attitudes. In addition, Lawson (2001) classifies three types of learning cycles: (a) descriptive, (b) empirical-inductive, and (c) hypothetical-deductive.

Other types of learning cycle approaches include the 4-E and 5-E learning cycles. The 4-E learning cycle approach is a four-phased teaching and planning model consisting of exploration, explanation (concept invention), expansion and evaluation (Yilmaz & Cavas, 2006). The 5-E learning cycle is a model consisting of: engage, explore, explain, elaborate and evaluate (Bybee & Sund, 1990). It incorporates the three original learning cycle phases while adding two more. The engage phase of the 5-E is designed to captivate students' attention and uncover their prior knowledge about concept(s), while the evaluate phase is an opportunity for the teacher to assess students' progress, as well as for students to reflect on their new understandings (Hanuscin & Lee, 2007).

This study has applied the 3-E learning cycle instructional model simply

because according to Türkmen (2006) the three phase learning cycle approach should be reinforced throughout the science curriculum and should be used in context at every grade level, in nearly every unit and that teachers should identify the potential hazards and/or precautions involved in scientific investigations and use simple key to classify objects and/or phenomena. Students must learn to evaluate conclusions based on scientific data. The teacher's main role in the learning cycle approach is to create social and intellectual climates, where collaborative, cooperative, constructivist and other learning methods are supported. The teacher also provides contexts for students to think critically, explore phenomena in their everyday lives, and solve meaningful problems meaningfully (Marek, Laubach, & Pedersen, 2003; Lawson, 2001).

The *exploration phase* typically consists of hands-on activities or field experience in which students gather and record data from their observations and measurements. The main purpose of this phase is that students are encouraged to learn through their own experience (Bybee, 2004). When a teacher introduces a learner to the materials or experience, the learner begins to discover the science concept through the questions. Students should be encouraged to dialogue with classmates or teammates to formulate explanations, and to make predictions. This phase makes available to the groups the experience of each individual. This stage involves finding out what happened within the individual during the experiment (Beisenherz, Dantonio, & Richardson, 2001; Lawson, 2001). In the *explanation phase*, the teacher takes an active role in leading the students to develop the concept. Students use their experience from exploration phase to develop an understanding of the science concept and explain the science concept with guidance from the teacher. During this phase, students make their own meaning

out of their observations. The role of the teacher is that of a mediator in assisting students to formulate these relationships and introduce the scientific term. This phase makes the experience practical, and if it is omitted or glossed over the learning is likely to be superficial. The crucial aspect of this phase is to move reality from inside the experience to the reality of everyday (Türkmen, 2006; Lawson, 2001). The *expansion phase* provides opportunities to directly apply the concept learned during the term introduction phase. Additional experiments, readings, films, and discussions can be done further. Students continue to expand the concepts by conducting more activities and using additional resources for investigation. Piaget described this phase as putting new thoughts in accordance with previous thoughts. During this time, the teacher should make an assessment of the students' abilities and thinking habits in investigating ideas. Students perform experiments that are explained by term introduction, and in this phase, new unexplained phenomena arise. The main purpose is to connect the newly learned concept to previously learned concept (Fleener & Marek, 1992).

The inquiry-based 3-E learning cycle model can be derived from the work of Jean Piaget's theory. The main point is how we connect the Piaget's mental functions with the learning cycle model (Türkmen & Usta, 2007). The 3-E learning cycle model directly corresponds to the Piagetian principles of assimilation, accommodation, and reorganisation. According to Lawson (2001, p. 633) "Exploration phase of the learning cycle provides experiences leading to assimilation and disequilibrium." This is because, when information received from the outside world is different from the mental structure, the students do not make enough sense of it in their minds, and so the students reach a state of disequilibrium, or if the information fits the external reality to their existing

cognitive structure, they can easily assimilate it in their mind (i.e., students are in the equilibrium phase). The exploration phase gets the students to interact with the laboratory environment while collecting data formally or informally.

The explanation phase of the learning cycle model is where students are expected to accommodate the new ideas (Türkmen & Usta, 2007). The teacher takes an active role in presenting the concept. Students redefine, change, or invent mental structures at this point. Students will be in the accommodation phase in this learning cycle stage, because students make their own meaning out of the observations. Either they succeed to make adjustments in each mental structure to make it fit their experience, or they do not construct the new mental structure and then fall in the disequilibrium phase again. Generally, accommodation phase will occur during the class discussion.

In the expansion phase, students continue to expand the concept by conducting more activities and using additional resources for investigation. The expansion of the ideas may involve "additional laboratory experiences, demonstrations, readings, questions, and/or problem sets" (Marek, Eubanks, & Gallaher, 1990, p. 831). The expansion phase matches to the organisation phase in the Piaget's mental functioning. This phase allows additional time for accommodation required by students needing more time for equilibrium. It also provides additional equilibrating experiences for students who have already accommodated the concepts, which were introduced. Its intent is to aid the organisation and generalisation of knowledge by adjustment of related mental structures and transfer from one context to another.

Inquiry-based learning cycle model has been used in many research work

and it has proven to be a potent instructional method. For instance, Yilmaz and Cavas (2006) explored the effectiveness of the 4-E learning cycle method on the 6th grade students' understanding of flowing electricity and their attitude towards science. Seventy-nine (79) students of which 40 were in the experimental group and 39 were in the control group from Izmir Cavit Ozyegin primary school took part in the study. Results of the posttest revealed that students taught using the 4-E learning cycle method were more successful than the students taught with the traditional method. Again, the 4-E learning cycle method produced statistically more positive attitude toward science after treatment. It was also found that almost all the students had misconceptions related to clashing current model. Students asserted that positive electricity moves from the positive terminal and negative electricity moves from the negative terminal of a power supply. The positive and negative electricity meet at a device and clash thereby powering the device and weakening current model that electrical current flows in one direction around a circuit, but that current gradually weakens because each device in the circuit uses up some of the current.

Ates (2005) investigated the effectiveness of the three-phase learning cycle method on university students' understanding of different aspects in resistive DC circuit. One hundred and fifty-two freshmen from the Absnt Izzet Baysal University in Turkey participated in the study. The results of the study indicated that the implementation of the learning cycle method enhances students' understanding of key aspects and concepts involved in DC circuits than the traditional method. The study also revealed that the learning cycle group students outperformed the traditional group students in understanding seven of the instructional objectives involved in electric circuits. However, the learning

cycle could not teach concepts such as conservation of current and explaining the microscopic aspects of current flow in a circuit.

In Ghana, Aboagye, Ossei-Anto and Johnson (2011) compared the three phase inquiry-based learning cycle approach to the traditional approach on senior secondary school students' understanding of selected concepts in direct current electricity. In all 101 students from two intact classes in two senior high schools in the New Juaben Municipality were randomly selected to participate in the study. The experimental group consisted of 59 students and the control group had 42 students. The results of the study showed that the experimental group which was instructed using the learning cycle approach performed better on the posttest compared to the control group who were instructed using the traditional approach. The results also revealed that the learning cycle approach was more effective for teaching most of the interrelated concepts and a number of different aspects of the selected concepts in direct current electricity than the traditional approach.

Combination of Inquiry-Based Real Hands-on and Computer Simulation Methods

This review focuses on the learning of concepts in electric circuits through two specific inquiry-based methods: real hands-on laboratory method and computer simulation method. In real hands-on laboratory method, students conduct hands-on experiments with *real* equipment and materials. In computer simulation method, students use computer-based simulation software to conduct hands-on experiments with *virtual* equipment and materials.

Real hands-on laboratory activities have a long history and a distinctive role in science education (Hofstein & Lunetta, 2004). Proponents of real hands-on laboratory activities have typically emphasised that authentic experiences with

real materials are essential for learning (National Science Teachers Association, 2007). Consequently, their argument against the use of simulations has been that computers deprive students of hands-on manipulation of real materials and so distort reality (Armstrong & Casement, 1998). Despite the criticism, simulations have become an increasingly popular alternative to real laboratories because they are safe, portable, highly customizable (Frederiksen, White & Gutwil, 1999), and potentially less expensive than real laboratories (Klahr, Triona, & Williams, 2007).

Empirical evidence shows that learning with simulations typically results in equal (Klahr et al., 2007; Yuan, Lee & Wang, 2010; Zacharia & Constantinou, 2008) or sometimes even better (Finkelstein et al., 2005; Chang, Chen, Lin, & Sung, 2008) conceptual learning outcomes than learning with real hands-on laboratory experimentations. Simulations have also been used successfully for learning in many domains including psychology (Hulshof, Eysink, & de Jong, 2006), mathematics (Tatar et al., 2008), physics (Wieman, Perkins, & Adams, 2008), chemistry (Winberg & Hedman, 2008), biology (Huppert, Lomask, & Lazarowitz, 2002), and medicine (Wayne et al., 2005). In the light of these, it is no surprise that many researchers suggest that the use of simulations should be increased in science education (Finkelstein et al., 2005; Zacharia & Constatinou, 2008). The most radical proposition has been that simulations should replace laboratories (Klahr et al., 2007; Triona & Klahr, 2003).

The above review shows how real hands-on laboratory activities and computer simulations are typically considered as competing and mutually exclusive methods in science teaching and learning. The real hands-on laboratory proponents' reluctant attitude toward the use of simulations, for instance, entails

that simulations have nothing good to offer for learners of science compared to real hands-on laboratory activities. Equally, the notion that simulations should replace laboratories assumes that because simulations produce at the minimum equal learning outcomes compared to laboratories, the benefits that simulations can provide to learners overlap the benefits of real laboratories. It implies, therefore, that both real hands-on and computer simulation activities have unique strengths and weakness.

Based on this, there are growing numbers of research works advocating for the combination of real hands-on laboratory and computer simulation activities instead of comparing the two learning environments. The reasons fall into the following four areas that all originate from the basic idea that both environments have unique strengths and weaknesses:

1. *Different learners, different representations*

The first motive to combine real hands-on laboratory and simulation activities is that different learners can benefit from different representations and availability of two representations increases the likelihood that students can learn with the representation that best matches their needs as compared to the situation when only a single representation is available (Jaakkola et al., 2011). The fact that real hands-on laboratory and simulation activities are typically considered as competing learning environments in science education indicates that advocates of each representation assume that there is an 'ideal' way to present and explore a domain, and that every student interprets the features of a learning environment in an 'ideal' or 'optimal' way. In reality, however, learning in a particular environment produces a considerable amount of variance in learning processes and outcomes between students. Kennedy and Judd (2007) analysed log files to

investigate the relationship between intended and observed user behaviours in a computer-based simulation environment in the domain of medicine. Their analysis revealed that only about a quarter of students used the simulation as the developers had intended.

Chang and colleagues (2008) who found that learning about the basic characteristics of an optical lens was significantly enhanced in simulation as compared to real laboratory reported that the students with higher abstract reasoning capabilities especially benefited from the use of simulation. Winn and his colleagues (2006) found no differences in overall learning outcomes between simulation and real laboratory environments, but their more fine-grained analyses revealed that the real experience was especially helpful and important for inexperienced students, because it helped contextualise learning, whereas the simulation made it easier for students (that apparently had some prior experiences) to connect what they learned from it to other content they learned in class. Veermans, van Joolingen and de Jong (2006) also found no differences in students' average learning outcomes between two simulation environments; however in their case factors mediating learning appeared to be very different between environments. These examples show that learning environments in general, and real hands-on laboratory and simulation activities in particular, are not always interchangeable as they have affordances toward different learners.

2. *Unique and complementary strengths*

The second motive to combine real hands-on laboratory and simulation activities is that both complement each other. Two different representations can highlight different aspects of the content (Ainsworth, 2006). For instance, as explained above, a simulation potentially makes it easier for students to learn the

basic principles of electric circuits because the embedded model is more transparent (e.g., visible current flow) and slightly simplified (e.g., ideal batteries). The real circuits can introduce more details, and thus deepen students' understanding. They can learn, for instance, that superficially different circuits can be functionally identical or vice versa; it is the configuration that matters (Finkelstein et al., 2005; McDermott & Shaffer, 1992). Since both representations highlight different aspects of the content, students can benefit from strengths of each in a combination environment or at least take advantage of their preferred representation (Tabachnek-Schijf & Simon, 1998).

3. *Comparison promotes deeper and more generalised understanding*

The third motive to combine real laboratories and simulations is that multiple representations allow learners to view the domain from different perspectives and compare the output of the representations. Making comparisons between two complementary representations can improve conceptual understanding, because comparisons help students focus on the common principles shared by the representations (Gentner, Loewenstein, & Thompson, 2003). Research on analogical learning shows that making comparisons between multiple representations or cases that overlap - in the present case laboratories and simulations - can activate deeper processing of the content and better understanding of the domain than use of only a single representation (real laboratory or simulation alone) (Kalyuga, Chandler, & Sweller, 1998; Kolloffel, Eysink, de Jong & Wilhelm, 2009; Thompson, Gentner & Loewenstein, 2000). Jaakkola and Nurmi (2008) found that students first constructed an electric circuit with a simulation and re-constructed that same circuit with real equipment immediately afterwards. Thus, students had a good opportunity to build cognitive links over the representations because both were available at all times (Ainsworth, 2006). The simulation provided students with an ideal model of electric circuits, which meant, among many other things, that the batteries were always fresh and the wires had zero resistance. Real batteries are almost never fresh and the wires in real circuits have some resistance. Consequently, this resulted in some discrepancies in the results of electrical measurement between the virtual circuits and the real circuits.

With a single representation, learners are easily drawn toward irrelevant surface features, which often result in overgeneralizations and understanding that is highly contextualised and superficial (Ainsworth, 2008; Gentner & Medina, 1998). In the Finkelstein et al. (2005) study, for instance, students who used real equipment to construct electric circuits were frequently in doubt about the effects that the colour of a wire could have on circuit behaviour. With two overlapping representations (such as real laboratories and simulations) of the domain, learners can compare and relate the structure of the representations, which allows them to both identify the shared invariant features of the representations and the features that are unique to each individual representation (Ainsworth, 2008; Gentner, Loewenstein & Thompson, 2003). This makes it easier to learn relevant domain knowledge, because those features that are shared across both representations also illustrate/highlight the central structures and principles of the target domain.

4. *Bridges the gap between theory and reality*

Combining and linking the use of real hands-on laboratory and simulation activities can bridge the gap between theory and reality (Ronen & Eliahu, 2000). Even a carefully designed simulation environment may not be sufficient to promote conceptual change. Tao and Gunstone (1999), for instance, were able to

alter students' conceptions of mechanics to some extent during the intervention by using a set of simulations, but a delayed post-test revealed that most of the students had regressed to their initial conception. It seems that the instruction was unable to activate fully students' prior conceptions: the learning took place in a simulation environment and the origins of the prior conceptions were on everyday experiences. Adding the real equipment could provide a solution to the above problem because the students could explore the extent to which the laws and principles they learned in a simulation environment do (and do not) apply in reality (Jaakkola & Nurmi, 2008). On the other hand, simulations can help the students to overcome difficulties in constructing and understanding real circuits (Finkelstein et al., 2005; McDermott & Shaffer, 1992). For instance, a simulation can be used as a point of reference when constructing and interpreting real circuits.

There are principally two different ways to combine real hands-on laboratory activities and computer simulation activities (or mix of any other representations). That is sequential or parallel combination. In a sequential combination, real hands-on laboratory and simulation activities are always used at different phases of the experimentation. In some studies (Zacharia, 2007; Zacharia et al., 2008), for instance, which consisted of three parts, enabled the students in the combination condition to use only real equipment in the first two parts of the intervention and only simulation in the last part. In a parallel combination, each experiment was conducted back-to-back with both representations. A study by Ronen and Eliahu's (2000), for instance, showed that students first constructed a real circuit, and then immediately after, constructed an identical virtual circuit using a simulation. Thus, the main difference between

sequential and parallel combinations is that real laboratories and simulations are never co-presented in the former, whereas they are always co-presented in the latter.

The decision as to whether to choose sequential or parallel combination can have considerable impact on students' performance. Interestingly, earlier studies that have combined real hands-on laboratory and simulation activities have predominantly chosen sequential combination (Campbell, Bourne, Mosterman, & Brodersen, 2002; Ronen & Eliahu, 2000; Zacharia, 2007; Zacharia et al., 2008) with only the study of Ronen and Eliahu (2000) among the earlier studies who used a parallel combination. In recent studies (Abdullah & Shariff, 2008; Farrokhnia & Esmailpour, 2010; Jaakkola & Nurmi, 2008; Jaakkola et al., 2011; Ünlü & Dökme, 2011), however, the parallel combination has been used. Both sequential and parallel combinations have their pros and cons. On one hand, the sequential combination may pose less cognitive load on students at the baseline, because they have to deal and monitor only one representation at a time. In the parallel combination students have to manage and coordinate between two representations. Tabachneck-Schijf and Simon (1998), for instance, have demonstrated that students may sometimes experience considerable difficulties in coordinating between and integrating information from two representations that are simultaneously available. On the other hand, in the parallel combination, real hands-on laboratory and simulation activities act simultaneously as sources of information that can help students to understand the domain under investigation - whatever is understood in one representation can be used to interpret and understand the domain (Ainsworth, 2006), and if something is missed in one representation, it can still be discovered in the other. This also

ensures that students have their preferred representation always available (Tabachnek-Schijf & Simon, 1998). Furthermore, assuming that the coordination between the representations will be productive and perhaps even necessary for proper understanding, then parallel combination will have clear advantages. The reason is that simultaneously available representations make the comparison and the mapping process between the representations easier and less demanding on learners' cognitive resources than studying the representations in isolation (Gentner et al., 2003; Thompson et al., 2000). When the representations are used sequentially, in isolation, students' understanding relies on a single representation at the time, and the mapping of information between the representations will be heavily dependent on memory retrieval which is a cognitively sensitive and computationally demanding process (Ainsworth, 2006; Kurtz, Miao & Gentner, 2001).

Research conducted in the framework of analogical learning, or more specifically analogical encoding, offers strong evidence for the effectiveness of parallel combination as compared to sequential combination at various levels of students' experience and expertise. Loewenstein, Thompson and Gentner (2003), for instance, asked experienced MBA students in two different conditions to analyse two overlapping negotiation cases that both entailed an optimal strategy for resolving a negotiation task. The outcome was that the students who analysed the cases simultaneously (parallel combination) were three times skilful in the use of the optimal negotiation strategies in a following real negotiation task than those who analysed the same cases in isolation (sequential combination). Gentner et al. (2003) were able to replicate the finding among undergraduate students with no prior negotiation experiences. Gentner, Loewenstein, and Hung (2007) have also

shown that learning with multiple representations facilitates understanding even among preschool children. The findings of the two latter studies are particularly important as they suggest that even novice learners can benefit from two overlapping representations, and that studying two cases simultaneously can be enlightening even when neither of the cases is well understood. The prototype models of analogical learning assumed that learning from analogical cases would suit only for relatively advanced and experienced learners. One of the main prerequisites in these models was that one of the cases needed to be well understood, because the well-understood case - which novice learners seldom have available - was used as an anchor and as a source of information to help students interpret and discover the properties of a corresponding, but less familiar, or more complex situation, the target (Gentner & Holoyak, 1997).

Cooperative Learning

Cooperative learning is a pedagogical practice that has attracted much attention over the last three decades because of a large body of research that indicates students gain both academically and socially when they have opportunities to interact with others to accomplish shared goals (Johnson & Johnson, 2002; Lou et al., 1996; Slavin, 1996). Cooperative learning has existed in several forms throughout history. One of the earliest pieces of evidence of cooperation appears in Ecclesiastes 4:9-10, 12:

> Two are better than one, because they have a good reward for their toil. For if they fall, one will lift up his fellow. But woe to him who is alone when he falls and has not another to lift him up. And though

a man might prevail against one who is alone, two will withstand him - a threefold cord is not quickly broken.

Cooperative learning refers to learning environments where small student groups learn together to achieve a common goal (Gilles & Ashman, 2003). Cooperative learning involves groups of students working to complete a common task (Siegel, 2005). Cooperative learning is also an arrangement in which students work in mixed ability groups and are rewarded on the basis of the success of the group as a whole (Woolfolk, 2001). This is typically done with groups of 2 – 5 students; the smaller the group, the better (Morgan & Keitz, 2010). Through interaction students learn to interrogate issues, share ideas, clarify differences, and construct new understandings (Mercer, Wegerif, & Dawes, 1999; Webb & Mastergeorge, 2003). In so doing, they learn to use language to explain new experiences and realities which, in turn, help them to construct new ways of thinking and feeling (Mercer, 1996). Moreover, when students work cooperatively together, they show increased participation in group discussions, demonstrate a more sophisticated level of discourse, engage in fewer interruptions when others speak, and provide more intellectually valuable contributions (Gillies, 2006; Webb & Farivar, 1999). By working cooperatively, students develop an understanding of the unanimity of purpose of the group and the need to help and support each other's learning which, in turn, motivates them to provide information, prompts, reminders, and encouragement to others' requests for help or perceived need for help (Gillies, 2003; Gillies & Ashman, 1998).

Students' peer interaction promotes cognitive processing (Hoy, Woolfolk, & O'Donnell, 2002; King, 2002) by supporting them to draw conclusions from the results of an inquiry (Morgan & Keitz, 2010). Peer collaboration offers three cognitive benefits: articulation, conflict, and co-construction (Crook, 1994). Questions can help students to clarify, justify, and, in some cases, alter their thinking. They can also help students identify alternative conceptions or areas needed to complete activities. Research has shown that cooperative learning has a positive influence on students' involvement in science and mathematics related materials (Ferreira, 2001). Students appear to enjoy working cooperatively and are willing to cooperative with others in the group (Krol, Janssen, Veenman & van der Linden, 2004). A particular research provides exceptionally strong evidence that cooperative learning result in efforts to achieve, more positive relationships, and greater psychological health than competitive or individualistic learning efforts (Johnson, Johnson & Holubec, 1994). Teachers also find satisfaction with the incorporation of cooperative learning groups (Linchevski & Kutscher, 1998).

The roots of cooperative learning lie deep in learning theories. Study of related literature provides a sound theoretical framework and conceptual base for cooperative learning. Most of the research works (Slavin, 1996; Johnson & Johnson, 1999; Morgan & Keitz, 2010) have described cooperative learning on three major theoretical perspectives: Motivational perspectives, Social cohesion perspectives, and Cognitive perspectives or theories. Motivational perspectives on cooperative learning assume that cooperative efforts are based on group rewards or goal structure (Slavin, 1995). Therefore, the members of the group are motivated to help group-mates in order to meet their own goals. Johnson and Johnson (1999) and Slavin (1995) have adopted motivational concerns of cooperative learning from behavioural and humanistic learning theories. Two important behaviourist concepts are group contingencies by Skinner and vicarious reinforcement or imitation by Bandura. The assumption of behavioural learning theory is that students will work hard on tasks that provide a reward and that students will fail to work on tasks that provide no reward or punishment (Morgan & Keitz, 2010).

Another theoretical perspective somewhat related to the motivational view point holds that the effects of cooperative learning on achievement are strongly mediated by the cohesiveness of the group, in the sense that student will help one another to learn because they care about one another and want each one to succeed. Johnson and Johnson (1999) discuss this perspective with reference to social interdependence theory. Social interdependence theory views cooperation as resulting from positive links of individuals to accomplish a common goal (Morgan & Keitz, 2010). According to Slavin (1996) a hallmark of the social cohesion perspective is an emphasis on team building activities in preparation for cooperative learning, and processing or groups self – evaluation during and after group activities.

Within cognitive theory, cooperation must precede cognitive growth. Cognitive growth springs from the alignment of various perspectives as individuals work to attain common goals. The cognitive developmental perspective is grounded in the work of Jean Piaget and Lev Vygotsky. Both Piaget and Vygotsky saw cooperative learning with more able peers and instructors as resulting in cognitive development and intellectual growth (Johnson, Johnson & Smith, 1998). Piagetian perspectives suggest that when individual work together, socio-cognitive conflict occurs and creates cognitive disequilibrium that stimulates perspective – talking ability and reasoning. Vygotsky's theories present knowledge as a societal product (Adodo & Agbayewa, 2011; Johnson & Johnson, 1999). Cognitivists try to look inside the mind to explore how thinking and learning take place. According to Slavin (1996) cognitive perspective holds that interaction among students will in themselves increase student's achievement for reasons which have to do with mental processing of information rather than with motivations.

There are many different research-based models of cooperative learning. One popular model is the Johnson and Johnson model. This model defines five essential elements of cooperative learning: (a) Positive interdependence: means that a gain for one student is associated with gains for the other students. According to Johnson and Johnson (1994) an effectively structured cooperative lesson is that students believe that they "sink or swim together" (p. 2). (b) Face-to-Face-Interaction: involves students working in environmental situations that promote eye contact and social space so that students can engage in discussions (Johnson & Johnson, 1999). This is where learners explain, argue, elaborate and link current material with what they have learned previously. (c) Individual accountability: that each person is responsible to the group and must be a contributing member, not someone who lets others do all the work. Each group member feels in charge of their own and their team mates' learning and makes an active contribution to the group. Thus there is no 'hitchhiking' for anyone in the group; everyone contributes (Kagan, 1990). (d) Interpersonal and small group skills or Social skills: each student must work at implementing the selected social skill and the instructor must monitor for this (Morgan & Keitz, 2010). The whole field of group dynamics is based on the premise that social skills are the key to group productivity (Johnson & Johnson, 1999). (e) Group processing: the opportunity to reflect on how well they functioned as a team and what they can do next time to be even better (Morgan & Keitz, 2010).

Constructing groups so that students work well together can be difficult. However, researchers have examined several possible methods of group formation, which can be categorised as either instructor-assigned or student-selected. Overall, there are two main grouping methods for cooperative learning under instructor assigned, namely heterogeneous and homogeneous or tracking or ability grouping. Heterogeneous composition groups are formed with the goal of creating balanced teams comprising individuals who represent a range of abilities (low-medium-high ability members), skills, major, gender, or ethnic background (van der Laan Smith & Spindle, 2007). This method has become very pervasive and is often included in guidelines for establishing cooperative learning (Watson & Marshall, 1995). A large number of cooperative learning studies have applied this way of grouping. Homogeneous composition groups, in contrast, are formed by instructors with the explicit goal of creating groups where each member is similar in ability (high-high, medium-medium or low-low abilities), skills, or other characteristics (Poole, 2008). There are still arguments about this grouping method because it leads to segregation, self-esteem, and feelings of inferiority especially on low achieving students and so should not be encouraged in our classrooms (Morgan & Keitz, 2010). According to Slavin and Braddock (1993) grouping by ability is ineffective. It is harmful to many students and inhibits the development of interracial respect, understanding, and friendship. It undermines democratic values and contributes to a stratified society (Slavin, 1993).

Again, empirical-inductive students have much lower academic achievement when placed in homogenous ability groups but their achievement increases when placed in mixed ability groups (Lou et al., 1996; Saleh & De Jong, 2005). In homogeneous ability groups, these students miss out on dialogue with hypothetical-deductive peers that have a better understanding of the material and are able to elaborate and explain it more effectively to them than other empirical-inductive students could. Empirical-inductive students will not be capable or confident enough to ask well developed questions when placed in homogenous ability groups. They are also exposed to very few positive behavior models in a group of all empirical-inductive students, unlike being in a group with hypothetical-deductive students who are often good models of positive behavior both academically and socially (Slavin, 1993). Heath (1999) and Slavin (1993) agree that these empirical-inductive students are prone to absenteeism, drop out, social problems, and are less likely to go to college. Empirical-inductive students suffer from missing out on the opportunities to observe, identify and simulate examples of a successful student (Poole, 2008). However, according to McEwin, Dickinson, and Jenkins (2003), a majority of American middle schools favour this method.

Some studies have shown that students in heterogeneous ability groups tend to learn more than students in homogeneous ability groups. The academic discussion and peer interaction in heterogeneous groups promote the development of more effective reasoning strategies (Lou et al., 1996). A meta-analysis study done by Lou, Abrami, and d'Apollonia (2001) indicates that low-ability students gain most from being placed in a heterogeneous ability groups because they receive individual guidance and assistance from their more able peers. Study by Hooper and Hannafin (1991) gives evidence that low ability students improved their performance more than 50% when grouped heterogeneously. Hooper and Hannafin also found that low-ability students' interaction was 30% more when placed in heterogeneous pairs and the student in heterogeneous pairs achieved and cooperated significantly more than the student in homogeneous pairs. Heterogeneous ability groups provide the potential for greater academic achievement in high-ability [HD) students. Research shows that HD students are called upon more in a heterogeneous ability groups to provide leadership, and explanations of the material through peer elaboration, or individual knowledge constructed from group interaction (Ballantine & Larres, 2007; Lou et al.; 1996; Saleh & De Jong, 2005). Ballantine and Larres (2007) have studied mixed ability groups and found that low-ability students benefited the most overall except in the area of leadership. Students that participated in the study found the experience to be "beneficial in terms of developing skills which will equip them for the workplace and lifelong learning" (Ballantine & Larres, 2007, p.132). Saleh and De Jong (2005) noted in their research:

> Giving explanations encourages a student to clarify and reorganise the material to make it understandable to others. Such elaborative talk helps both parties to understand the material better...The explainer benefits from the cognitive restructuring involved in peer tutoring in that it might trigger the detection and repair of misconceptions and knowledge gaps (p.106).

These studies all conclude that hypothetical-deductive students that assume the role of the teacher will experience increased understanding and personal achievement. Mixed-ability group interaction resulting in an increased clarification of material and new learning techniques for empirical-inductive while restructuring and solidifying curriculum in the hypothetical-deductive students, could ultimately reduce the demands placed on instructors (Tieso, 2005).

Student-selected groups are formed by students themselves without intervention by an instructor. Typically, the students who seek this formation method are individuals who have had prior social or academic interactions with one another (Chapman, Meuter, Toy, & Wright, 2006; Swanson, Gross, & Kramer, 1998). Friendship grouping - a student-selected method- is another issue to consider in promoting group interactions (Thanh & Gillies, 2010). There is evidence that students who know and like each other benefit most from working together as they tend to accept more responsibility for their learning and are more motivated to achieve their goals than students who are not friends (Abrami, Chambers, Poulsen, DeSimone, & Howden, 1995). Researchers remain split about the relationship between group members' friendship and outcomes, and the prior published work on friendship among students has left important areas in need of inquiry. First, consider the research that highlights the benefits of friendship in collaborative task performance. Newcomb and Bagwell (1995) found friendship collaborations to have more intense social activity, more frequent conflict resolution, more effective task performance, and to be marked by reciprocal and intimates properties of affiliation, greater equality, mutual liking, closeness, and loyalty. Theorists have also suggested that the psychological context of friends collaborating may be associated with productivity and learning gains (Azmitia, 1996; Shah & Jehn, 1993), as well as social and emotional growth (Newcomb & Bagwell, 1995).

The ease of establishing a shared problem-solving space in groups of friends has also been linked to successful outcomes, arguably from the group members' familiarity with the prior knowledge, communicative strategies, and thinking styles of their partners (Barron, 2003). Others believe that working with friends yields lower-quality outcomes because friends have more off task, disruptive behaviour, stronger pressures to agree, and reluctance to be critical of each other's' ideas (Dutson, Todd, Magleby, & Sorensen, 1997; Zajac & Hartup, 1997). Prior work found that groups of friends both disagree more frequently (Shah & Jehn, 1993) and are more concerned with resolving disagreements (Newcomb & Bagwell, 1995) than those composed of non-friends. Mitchell, Reilly, Bramwell, Solnosky and Lilly (2004) investigated the preferences for teacher-selected versus student-selected groupings in high school science classes. The sample consisting of 139 students in five science classes participated in this study. Classes were randomly assigned to condition: Teacher-selected or student-selected. In teacher-selected classes, the teacher chose the members of each group; in student-selected classes, the students chose their group mates. Results revealed a decrease in willingness to choose one's group mates. Focus group data indicated that students felt obligated to choose friends as group mates, and low-achieving students questioned the value of working with similar others.

Research however, advocate for heterogeneous and friendship groupings based on the academic benefits they bring (Abdullah & Shariff, 2008). This formed the basis of investigating the effects of heterogeneous-ability and friendship cooperative learning groupings. Thanh and Gillies (2010) conducted a study on group composition of cooperative learning to see whether heterogeneous grouping works in Asian classrooms based on the recognition heterogeneous grouping has gained in Western countries. This study aimed to investigate how Vietnamese students should be grouped so that they could maximise their opportunities to learn. The study was in two parts: a pilot study and an intervention. The pilot study included 20 students and was conducted for four weeks. The intervention consisted of 145 students and lasted for eight weeks. In both studies, students answered a questionnaire survey and 10 students were interviewed. The results of both studies showed that friendship grouping was more preferred.

Galton, Gray and Rudduck (2003) found that some students liked working with friends who were similar in ability to themselves (symmetrical partnerships), while others liked working with friends who were different from themselves, either in levels of competence or ways of thinking (asymmetrical partnerships). Research has raised concerns about the heterogeneity of friendship in symmetrical partnerships which is the common group composition of the two (Miell & MacDonald, 2000). The danger in this type of group composition is that members of the group may be of the same ability which in effect brings back the criticisms raised against homogeneous grouping (Abdullah & Shariff, 2008). It is, therefore, likely that students in the heterogeneous-ability cooperative learning group will perform better in scientific reasoning and conceptual understanding of electric circuits than students in the friendship cooperative learning group on the basis that the friendship group may either be all low ability students, all medium ability students, all high ability students or a mixture. This formed the basis for hypothesis one.

Scientific Reasoning

Scientific reasoning also called scientific thinking, logical thinking or higher thinking ability has been the subject of a long line of research within psychology and education. Plotnik (2006) defined scientific reasoning as a mental process that involves using and applying knowledge to solve problems, make decisions, and achieve goals. Scientific reasoning or thinking is defined as the application of the methods or principles of scientific inquiry to reasoning or problem-solving situations, and involves the skills implicated in generating, testing and revising theories, and in the case of fully developed skills, to reflect on the process of knowledge acquisition and change (Koslowski, 1996; Kuhn & Franklin, 2006; Wilkening & Sodian, 2005). Scientific reasoning can be developed, improved and transferred through training and practice (Bao et al., 2009). Fenci (2010), She and Liao (2010), Abdullah and Shariff (2008) and Abdullah and Abbas (2006) found out that students who were exposed to inquiry-based teaching made significant gains in scientific reasoning skills. Strong scientific reasoning abilities have also been found to positively correlate with course achievement on conceptual understanding (Cavallo, Rozman, Blickenstaff, & Walker, 2003; Johnson & Lawson, 1998), improvement on concept tests (Coletta & Phillips, 2005; She & Liao, 2010), and success on transfer of scientific reasoning questions (Ates & Cataloglu, 2007; Jensen & Lawson, 2011).

Scientific reasoning uses arguments which are sets of statements or propositions each consists of premises and conclusion (Khan & Ullah, 2010). Conclusions are derived from the statements (premises). Scientific reasoning can either be a deductive (deduction) or it can be an inductive (induction) processes

(Plotnik, 2006; Zeineddin & Abd-El-Khalick, 2008). In an argument, for the assumption that the premises is true and it is impossible that the conclusion is false, the argument is deductive, but if the truth of conclusion is probable then it is inductive argument (Khan & Ullah, 2010). Deductive reasoning or deduction consists of arguments where if the premises are assumed to be true, then it is impossible for the conclusion to be false (Koenig, Schen, & Bao, 2012). Deductive reasoning begins with making a general assumption that one knows to be true and then drawing specific conclusions based on the assumption (Khan & Ullah, 2010). For example:

All the lecturers in UCC are good researchers; Mr. Ahithophel is a Lecturer in UCC.

Therefore

Mr. Ahithophel is a good researcher.

The conclusion drawn using deduction is reliable. One can trust the truth of result (truth preserving). A theory, therefore, can be tested either by logical comparison of the conclusions with each other, investigating the logical form of the theory (to find out whether it is empirical or scientific), comparing it with other theories or by testing the theory using the way of empirical applications of the conclusions derived from it (Khan & Ullah, 2010; Koenig, Schen & Bao, 2012).

Inductive reasoning or induction on the other hand, is the process of reasoning in which it is believed that the premises of an argument support the truth of conclusion, but they do not ensure its truth. It is true even for a good argument, where it is quite possible that there will be false conclusion even if the premise is true (Khan & Ullah, 2010). An inference is said to be inductive inference if it passes from singular statements to universal statements or theories. That is to say that induction leads from specific truth to general truth (knowledge expanding). Inductive inferences that we draw from true premises are not fully reliable, because they may take us to the false result from true premises (Khan & Ullah, 2010). Induction takes individual instances and based on those instances, some generalization is made. For example:

Students A, B, and C in the library read.

Based on the above premise, a general conclusion is drawn as following.

All the students in the library read.

Many scholars, like David Hume, Karl Popper and David Miller have discouraged inductive reasoning. Although inductive reasoning exists everywhere in science, it is philosophically controversial (Khan & Ullah, 2010).

The development of thinking abilities be it inductive or deductive is well-discussed in the world of education. Fah (2009) stated that the higher the ability of a person to think in an abstract way, the higher the person will function effectively in society. Hence, the improvement of formal reasoning and thinking abilities among students is one of the aims of science education at all levels of schooling. Cognitive development theory, a well-known theory proposed by Jean Piaget has 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) (Plotnik, 2006). The main difference among these stages of cognitive development though criticised and revised (Carlson & Buskist, 1997; Griffiths & Gray, 1994) is the mode of thinking. Students at formal operational stage can think logically about abstract propositions and test hypotheses systematically and at the same time, they become concerned with the hypothetical, the future and ideological problems (Fah, 2009). The latter two stages of Piaget's theory are relevant to scientific reasoning in that these are the stages during which advanced reasoning skills begin to develop (Remigio et al., 2014). Lawson (1995) renamed concrete operational stage as empirical-inductive (EI) thought and the formal operational stage as hypothetical-deductive (HD) thought. Empirical-inductive thought involves testing hypotheses about unobservable entities which means students at this level operate on the assumption that 'I see, I believe and I know.' This thinking pattern comprises class inclusion, conservation, and serial ordering (conservational reasoning). Conservational reasoning is where the individual applies conservation thinking to perceptible objects and properties.

Hypothetical-deductive (HD) thought on the other hand, involves skills associated with testing hypotheses about observable causal agents (Remigio et al., 2014). HD reasoning involves starting with a general theory of all possible factors that might affect an outcome and forming a hypothesis; then deductions are made from that hypothesis to predict what might happen in an experiment. According to Kuhn (2010), the very beginning of the HD reasoning process involves identifying an appropriate question as the object of investigation and the ability to generate one or more hypothesis is a challenging one and contributes significantly to success. HD reasoning is important in concept construction because students typically do not come to the learning situation as blank slates rather, they come with alternative conceptions (i.e., hypotheses) that must be modified or replaced by scientific conceptions. Thus, concept construction often engages hypothetical-deductive reasoning skills (Lawson & Weser, 1990; Lawson et al., 2000). Through HD reasoning and experimentation, students can test their preconceptions against scientific concepts and find out which one match experimental results. This promotes conceptual change (Fah, 2009). This reasoning formed the basis for hypotheses two, five and six on changes in conceptions.

Researchers (Abdullah & Shariff, 2008; Lawson, 1995; Lawson, 2001, Lawson et al., 2000; Remigio et al., 2014) have identified five different thinking patterns to include: proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. According to Lawson (1995), proportional reasoning means the individual recognises and interprets relationships between relationships in situations described by observable or theoretical variables. Controlling variables means the individual considers all the known variables in a given hypothesis and designs a test that controls all variables except the one being investigated. Probabilistic reasoning means the individual recognises that natural phenomena themselves involve chances variation and that any conclusions or explanations must require likelihood considerations. Correlational reasoning means the individual recognizes the extent to which changes in one variable are incidental to the changes in another variable. Combinatorial reasoning means the individual is involved in the coordination and correspondence, arrangement with repetitions, permutations, combinations and reversible systems of reference.

In adolescent classrooms, there is the high possibility of finding both HD and EI reasoning students even though at this stage in their intellectual development according to Piaget, they should be operating at the formal operational level where they can think abstractly (Abdullah & Shariff, 2008). However, since there are defects in Piaget's cognitive development theory, it is important for teachers to identify where students in their classes operate so that appropriate heterogeneous-ability groupings can be formed for optimal gains in students' achievements. By this, the empirical-inductive (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 student's ability towards hypothetical-deductive reasoning (Lou et al., 1996). These consequently help the EI students to clarify their own mental models and foster better understanding concepts in electric circuits (Abdullah & Shariff, 2008). Based on this argument, it is likely both HD and EI students in the HACL group will develop scientific reasoning and conceptual understanding of electric circuits than the HD and EI students in the FCL group. This formed the basis for hypothesis three and four.

Conceptual Change

Conceptual change is defined as a process in which an already existing concept is abandoned or modified to agree with the theory held by the scientific community (Hewson, 1992; Özdemir & Clark, 2007). The term conceptual change as widely used refers to the fundamental restructuring of already existing or pre-instructional knowledge (Vosniadou, 1994). Duit and Treagust (2003) held that in a general sense, conceptual change denotes learning pathways from students' pre-instructional conceptions to the science concepts to be learned. The interpretation of student responses as driven by alternative conceptions suggests that learning may involve changing a person's conceptions in addition to adding new knowledge to what is already there (Hewson, 1992). Hewson and Hewson (1992) also suggested that conceptual change can be seen as a change of status attributed to a particular conception. They stressed that while the student's alternative conception was losing its status, the new concept began to gain its status and therefore it was understood, accepted and seen as useful. They also emphasised that conceptual change should not be seen as a situation in which students' existing conceptions are completely deleted or exchanged for the new concept.

The term 'change' should not be misunderstood as being an exchange of pre-instructional conceptions for the science concepts, rather, the term 'change' as used in conceptual change refers to learning in such domains where pre-instructional conceptual structures of the learners have to be fundamentally structured in order to allow understanding of science concepts. Students' conceptual ideas are based on personal experiences and require real changes in thinking, but, students are often not open to such new ideas (Özdemir & Clark, 2007). Based on this, a rather radical approach is needed to change pre-existing concepts. With this in mind, Posner et al. (1982) proposed the first conceptual change theory, which is a combination of two theories: (1) Kuhn's theory of paradigm shift derived from normal science and scientific revolution and (2) Piaget's theory of assimilation and accommodation. Posner et al. proposed that if a learner's current conception is functional and if the learner can solve problems within the existing conceptual schema, then the learner does not feel a need to change the current conception.

According to Hewson (1992), one of the common instructional strategies capable of fostering conceptual change is inquiry-based or constructivist teaching strategies because it takes cognizant of students' initial ideas before formal instruction. Such strategies confront students with discrepant events that contradicts their existing conceptions which is intended to invoke disequilibration or conceptual conflict that induces students to reflect on their conceptions as they try to resolve the conflict (Özdemir & Clark, 2007). New concept is assimilated by pre-conceptual structure and the conceptual structure is accommodated if a students' existing concept contradicts with the newly learnt concept. Following this, the student have to undergo the process of accepting, using and integrating the new concepts in their lives and even applying them to new situations (Özdemir & Clark, 2007). Posner et al. hypothesized that there are four conditions for conceptual change to occur. The conditions are as follows:

i. Dissatisfaction: The learners must first realise that there are some inconsistencies in their thinking and that their way of thinking does not solve the problem at hand.

ii. Intelligibility: The concepts should not only make sense, but, the learners should also be able to regurgitate the argument and ideally be able to explain that concept to classmates.

iii. Plausibility: The new concept must make 'more' sense than the old concept. It must have the capacity to solve the problem better. The learners should be able to decide on their own how this new concept fits into their ways of thinking and recall situations where this concepts could be applied.

iv. Fruitfulness: The new concept should do more than merely solve the problem at hand; it should also open up new areas of inquiry.

According to Hewson (1992), if the new conception follows all the four conditions, learning proceeds without difficulty. However, science educators face several difficulties when they attempt to put into practice the four proposed conditions in order to promote conceptual change. Based on the above, Strike and

Posner (1992) criticised the theory of Posner et al. as being too linear and overly rational, based on the assumption that learners have well-articulated alternative conceptions or misconceptions for most of science concepts.

The terms ‘conceptual change’ and ‘conceptual understanding’ are often used interchangeably in literature. However, there is a sharp difference between the two terms. While conceptual change is the ability of students’ to change their alternative conceptions for the scientifically correct concepts (Hewson, 1992; Özdemir & Clark, 2007), conceptual understanding reflects a student's ability to reason in settings involving the careful application of concept definitions, relations, or representations of either (National Research Council, 2001). Students demonstrate *conceptual understanding* when they provide evidence that they can recognise, label, and generate examples of concepts; use and interrelate models, diagrams, manipulatives, and varied representations of concepts; identify and apply principles; know and apply facts and definitions; compare, contrast, and integrate related concepts and principles; recognise, interpret, and apply the signs, symbols, and terms used to represent concepts (National Council of Teachers of Mathematics, 2000). Students can change their conceptions without being able to apply the concepts to novel situations, however, adequate understanding of concepts can lead to conceptual change (National Assessment of Educational Progress, 2003; National Council of Teachers of Mathematics, 2000). It can be inferred that conceptual change is a necessary condition for conceptual understanding but not a sufficient conception.

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. These learning outcomes include conceptual understanding, scientific reasoning and conceptual change (Bybee, Powell, & Trowbridge, 2008). 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 (Piaget, 1952), social interaction (Vygotsky, 1978) and conceptual change (Posner et al., 1982).

Piaget (1952) 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 (Carlson & Buskist, 1997; Griffiths & Gray, 1994) 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 (Fah, 2009; Remigio et al., 2014). 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.

Vygotsky (1978) 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. Posner et al. (1982) on their part believe that one goal of instruction is to facilitate change in students' conception of the world. They hypothesised that there are four essential cognitive conditions for conceptual change to occur: dissatisfaction, intelligibility, plausibility and fruitfulness. The major goal is to create a cognitive conflict to make a learner dissatisfied with his or her existing conception. Then, the learner may accept a normative view as intelligible, plausible, and fruitful. This view has been a very influential theory to determine a learner's specific conceptions that result from the interaction between beliefs and knowledge of the learner. Based on these three theories, a theoretical model of this study is presented in Figure 1.

The phases in 3-E inquiry-based learning cycle can promote conceptual understanding, scientific reasoning and conceptual change 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.

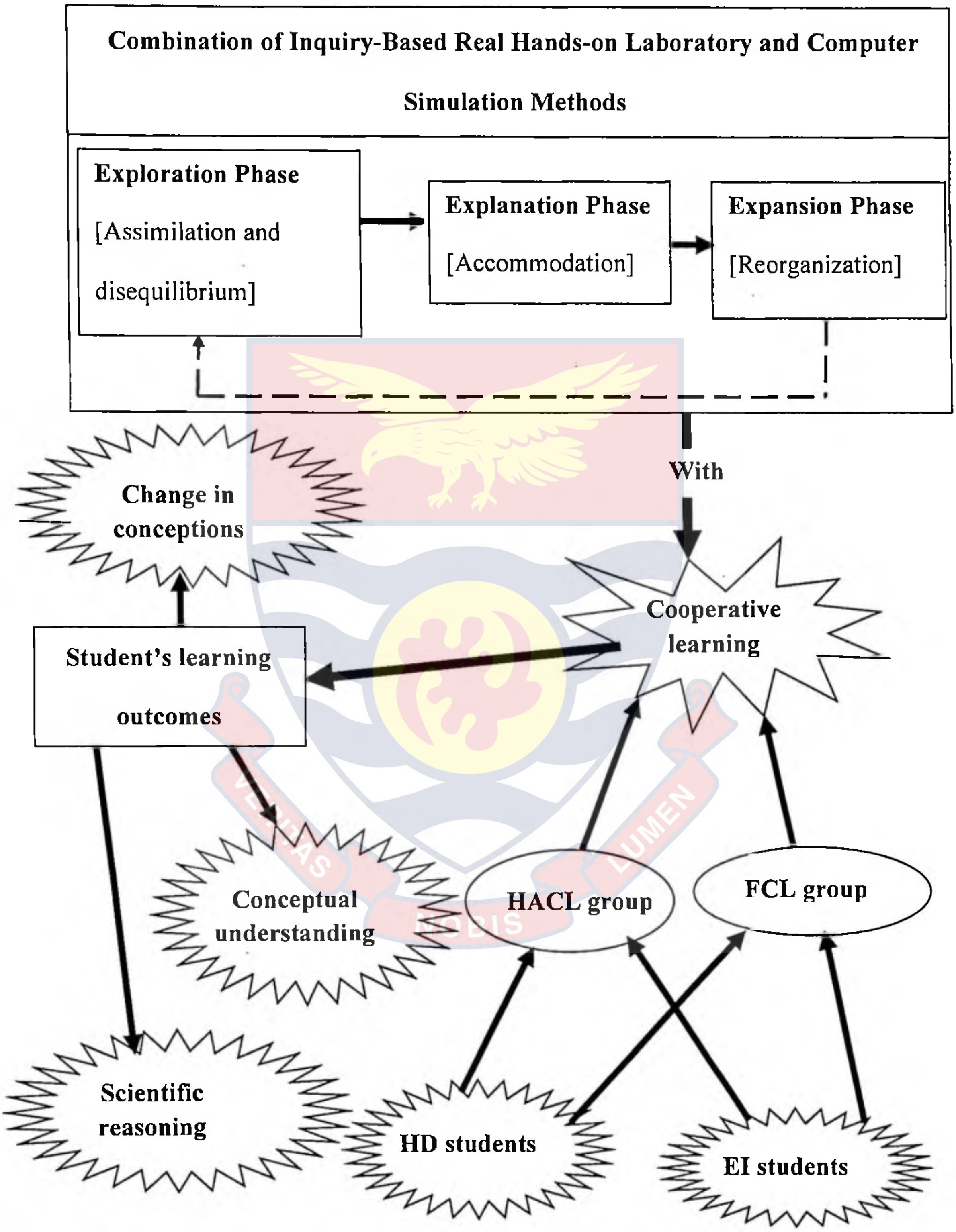

Figure 1: Theoretical model of the study.

Author constructed framework

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, reasoning and change in conception 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, scientific reasoning and change in conceptions. 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 (Abdullah & Shariff, 2008; Lou et al., 1996). 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.

Real Hands-on Method and Computer Simulation Method, and their Combination on Students' Conceptual Understanding of Electric Circuits

There are now a growing number of studies comparing learning from computer simulations to learning in real hands-on laboratory activities. These studies can be divided into two groups. The first group compares computer simulation activities with real hands-on laboratory activities. The second group compares real hands-on laboratory activities, computer simulation activities and some combination of computer simulation and real hands-on laboratory activities.

The first group of studies, Chang, Chen, Lin, and Sung (2008) investigated the effect of learning support in simulation-based physics learning of optics in three learning models: experiment prompting, a hypothesis menu, and step guidance. A simulation learning system was implemented based on these three models, and the differences between simulation-based learning and traditional laboratory learning were explored in the context of physics studies. The effects of the support type on learning performance were also quantified. In second-year junior high school students it was found that the outcome for learning about the basic characteristics of an optical lens was significantly better for simulation-based learning than for laboratory learning. They also investigated the influences of different learning models on the students' abstract reasoning abilities, which showed that the different learning models do not have different effects on individuals with different abstract reasoning abilities. However, they found that students who are better at higher abstract reasoning benefit more from simulation-based learning, and also that the learning results are better for experiment prompting and a hypothesis menu than for step guidance.

Kumar et al. (2011) examined the impact of computer simulation supported learning on the conceptual understanding of elementary and secondary teachers of concepts in current electricity. The participants consisted of 40 teachers comprising of 22 elementary teachers and 18 secondary teachers who attended the current electricity computer simulation Constructing Physics Understanding (CPU) project workshops held at Florida Atlantic University. The results showed that the overall gain for elementary teachers was significantly higher than that for secondary teachers although the current electricity computer simulation supported CPU project workshops had a positive impact on the conceptual understanding of both elementary and secondary teachers. Again, the overall gain for females was significantly larger than that for males although both males and females gained substantially from the workshops. The authors recommended that simulations should become an integral part of science learning as efforts are being made to improve teachers' conceptual understanding of science and through teachers, student learning of science in classrooms across the globe.

Huppert, Lomask and Lazarowitz (2002) compared a group of students who followed a combination of traditional lecture and laboratory-based instruction on microbiology with a group who learned with a computer simulation integrated in the laboratory. The aims were to investigate the computer simulation's impact on students' academic achievement and on their mastery of science process skills in relation to their cognitive stages. The sample consisted of 181 students from five tenth grade classes in Israel. The results indicate that the concrete and transition operational students in the experimental group achieved significantly higher academic achievement than their counterparts in the control group. The higher the cognitive operational stage, the higher students' achievement was, except in the control group where students in the concrete and transition operational stages did not differ. Girls achieved equally with boys in the experimental group. Students' academic achievement may indicate the potential impact a computer simulation program can have, enabling students with low reasoning abilities to cope successfully with learning concepts and principles in science which require high cognitive skills.

A number of other studies found no differences in outcomes between simulated environments and real laboratories. For instance, Baser and Durmus (2010) investigated the effectiveness of computer supported versus real laboratory inquiry learning environments on the understanding of direct current electricity among pre-service elementary science teachers. The main aim of the study was to compare the changes in conceptual understanding of direct current electricity (DCE) in virtual (VLE) and real laboratory environment (RLE) among pre-service elementary school teachers. The participants were 87 pre-service elementary school teachers enrolled in two classes of science education course at Abant Izzet Baysal University in Turkey. Participants in the VLE group used computer simulations to perform given tasks, whereas those in the RLE group used real laboratory apparatus. The results showed that computer supported inquiry and real laboratory inquiry teaching had the same effect on students' understanding of concepts in current electricity. The study also revealed that students' attitudes toward physics is a good predictor for their achievement related to direct current electricity. Based on the findings the authors concluded that students' conceptual understanding in electricity can be improved not only by physical manipulations but also by computer simulations.

Bayrak and Kanli (2007) compared the effects of computer based learning and the laboratory based learning on students' achievement regarding electric circuits. The sample comprises of 28 ninth grade secondary school students in Azdavay district of Kastamonu province in Turkey who were randomly sampled into control and experimental groups. The results showed that there is no significant difference in achievement between students instructed with real laboratory experience and those instructed with computer simulation. The authors concluded that the computer based learning is as effective as the laboratory based learning on students' achievement.

Zacharia and Constantinou (2008) compare the effect of experimenting with physical or virtual manipulatives on undergraduate students' conceptual understanding of heat and temperature. A pre-post comparison study design was used to replicate all aspects of a guided inquiry classroom except the mode in which students performed their experiments. This study is the first on physical and virtual manipulative experimentation in physics in which the curriculum, method of instruction, and resource capabilities were explicitly controlled. The participants were 68 undergraduate students in an introductory course and were randomly assigned to an experimental and a control group. The result indicates that both modes of experimentation are equally effective in enhancing students' conceptual understanding. This result is discussed in the context of an ongoing debate on the relative importance of virtual and real laboratory work in physics education.

A second group of studies found advantages for the combination of computer simulated and real environments. There are only a few empirical studies, most of them conducted in the domain of electricity, that have investigated the relative effectiveness of combining laboratories and simulations in science education as compared to using the two representations alone. Ronen and Eliahu (2000) in their study on simulation - a bridge between theory and reality, examined the role of a simulation as a potential aid that may help students to bridge the gap between theory and reality, in the case of electric circuits. Sixty-three pairs of students aged about 15 years were presented with two tasks involving real circuits. An open simulation environment was available as an optional aid for the experimental group. In the experimental group the students had also an opportunity to use a simulation to build and sketch circuits (in control group they could sketch only on paper), but they were not explicitly instructed to use the simulation, as the computer monitor was turned off. The outcome was that those students who decided to use the simulation were more efficient in drawing corresponding schematics and more accurate (fewer errors) at constructing requested real circuits than students who didn't use the simulation. The use of the simulation contributed to students' confidence and enhanced their motivation to stay on-task. The detailed analysis revealed the role of the simulation as a source of constructive feedback, helping students identify and correct their misconceptions and cope with the common difficulties of relating formal representations to real circuits and vice versa.

Campbell et al. (2002) investigated learning of electricity among beginning electrical engineering students. In the laboratory condition the students used only real equipment, whereas in the combination condition they conducted first all the experiments virtually using a simulation, and then in the end, repeated two of the virtual experiments with real equipment. The outcome was that the students in the combination condition outperformed the students in the laboratory condition in a written lab and theory knowledge in the post-test.

Zacharia (2007) investigated the value of combining real experimentation (RE) with virtual experimentation (VE) with respected to changes in undergraduate students' conceptual understanding of electric circuits. The sample consisted of 88 undergraduate students who were enrolled in an introductory course in physics in a university in Cyprus. The participants were randomly assigned to an experimental group (45 students) and control group (43 students) with ages ranging from 20 to 22 years. The control group used the RE method only and the experimental group used both RE and VE methods. Both groups used the same inquiry-based curriculum materials on electric circuits. However, participants in the control group used RE to conduct all the experiments in the physics laboratory, whereas, participants in the experimental group used RE to conduct the experiments of Parts A and B in the physics laboratory and VE to conduct the experiments to Part C on a computer. The results indicated that the combination of RE and VE enhanced students' conceptual understanding more than the use of RE alone. A further analysis showed that the use of VE enhanced students' understanding of Part C of the curriculum more than the use of RE. Another interesting finding in the study is that the study showed that the majority of both groups appeared to share about the same conceptions either scientifically accepted or not, both before and after the Part C of the research interventions. The problem with this study appear to show that VE was used only in Part C of the entire study and so it is methodologically wrong to generalize that the combination of RE and VE is superior to RE only in promoting conceptual understanding.

Jaakkola and Nurmi (2008) conducted a study on fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities simply because computer simulations and laboratory activities have been traditionally treated as substitute or competing methods in science teaching. The aim of this experimental study was to investigate if it would be more beneficial to combine simulation and laboratory activities than to use them separately in teaching the concepts of simple electricity. The sample comprises of 66 elementary school students who were placed into three different learning environments: computer simulation, laboratory exercise and a simulation–laboratory combination. The results showed that the simulation–laboratory combination environment led to statistically greater learning gains than the use of either simulation or laboratory activities alone, and it also promoted students' conceptual understanding most efficiently. There were no statistical differences between simulation and laboratory environments. The results highlight the benefits of using simulation along with hands-on laboratory activities to promote students' understanding of electricity. The authors recommended that a simulation can help students to first understand the theoretical principles of electricity; however, in order to promote conceptual change, it is necessary to challenge further students' intuitive conceptions by demonstrating through testing that the laws and principles that are discovered through a simulation also apply in reality.

Farrokhnia and Esmailpour (2010) investigated the impact of real, virtual and comprehensive (combination of virtual and physical) experimenting on students' conceptual understanding of DC electric circuits and their skills in undergraduate electricity laboratory. This study involved 100 undergraduate students of Shahid Rajaei Teacher Training University of Tehran who were randomly divided into an experimental group 1 (Real group), experimental group 2 (Virtual group) and experimental group 3 (Comprehensive group). The results showed that students in the comprehensive group outperformed their counterparts in the real group in both conceptual understanding and their skills, but there was no noticeable difference in performance between the comprehensive group and virtual group and also between the virtual group and real group. Based on the findings the authors recommended that in the right conditions, simulation can be substituted effectively for real laboratory equipment but we do not suggest that any simulations necessarily promote conceptual learning and development of skills, rather well designed ones are useful tools for a variety of contexts which can promote student learning.

Jaakkola, Nurmi and Veermans (2011) compared the learning outcomes of students using a simulation alone (simulation environment) with outcomes of those using a simulation in parallel with real circuits (combination environment) in the domain of electric circuits, and to explore how learning outcomes in these environments are mediated by implicit (only procedural guidance) and explicit (more structure and guidance for the discovery process) instruction. The participants were 50 fifth and sixth grade students from three different classrooms of one urban Finnish elementary school. Matched-quartets were created based on the pretest results of 50 elementary school students and divided randomly into a simulation implicit (SI), simulation explicit (SE), combination implicit (CI) and combination explicit (CE) conditions. The results demonstrated that the instructional support had an expected effect on students' understanding of electric circuits when they used the simulation alone; pure procedural guidance (SI) was insufficient to promote conceptual understanding, but when the students were given more guidance for the discovery process (SE) they were able to gain significant amount of subject knowledge. A surprising finding was that when the students used the simulation and the real circuits in parallel, the explicit instruction (CE) did not seem to elicit much additional gain for their understanding of electric circuits compared to the implicit instruction (CI). Instead, the explicit instruction slowed down the inquiry process substantially in the combinational environment (CE). Although the explicit instruction was able to improve students' conceptual understanding of electric circuits considerably in the simulation environment, their understanding did not reach the level of the students in combination environment. These results suggest that when teaching students about electric circuits, the students can gain better understanding when they have an opportunity to use the simulation and the real circuits in parallel than if they only a computer simulation available, even when the use of the simulation is supported with the explicit instruction.

Ünlü and Dökme (2011) investigated the effect of combining anology-based simulation and laboratory activities on Turkish elementary school students' understanding of simple electric circuits. The main aim of the study was to investigate whether the combination of both analogy-based simulation and laboratory activities as a teaching tool was more effective than utilizing them separately in teaching the concepts of simple electricity. The quasi-experimental design that involved 66 seventh grade students from urban Turkish elementary school was used. The groups were randomly assigned to the control group I in which the real laboratory activities were used, to the control group II in which analogy-based simulation activities were used and to the experimental group in which both analogy-based simulation and laboratory activities were used together. The results indicated that the combination of both analogy-based simulation and laboratory activities caused statistically greater learning acquisition than the analogy-based simulation and laboratory activities did alone. However, on the contrary their expectations, there was no statistical difference between the control I and control II groups. The results highlighted that environments of laboratory and computers are complementing each other, not to prefer one to another in teaching the concepts of simple electricity.

It can be concluded from the review on combination of the two methods that learning with multiple representations or from multiple cases can, and often does, result in better learning outcomes than learning from a single representation or case. Though the above results could mean that combining real laboratories and computer simulations can provide additional benefits for learning of scientific knowledge and scientific reasoning as compared to learning with real laboratories and simulations alone, the incomplete designs of these studies leave plenty of room for alternative explanations. Firstly, the combinational groups had double modes of instruction whereas the simulation only and real laboratory only groups had a single mode of instruction. Secondly, the effect of time as a factor of instruction was not taken into consideration during their conclusions. The combinational groups definitely had more time of instruction than the single representation groups though in all the groups the same content or curriculum materials were covered. Based on this, the current study is designed such that equal opportunities are given to all the groups in terms of the number of representations, time of instruction and curriculum materials.

Empirical Studies on Scientific Reasoning

Thoron and Myers (2012) investigated the effect of inquiry–based agriscience instruction on student scientific reasoning. The study investigated the effect of two teaching methods (inquiry–based instruction and the subject matter approach) on agriscience student scientific reasoning. Fifteen agriscience education classes confined within seven secondary schools across the United States participated in the study. In all, 305 students participated in the study which comprised 170 students in the inquiry–based instruction group and 135 students in the subject matter group. The results showed that students taught through inquiry–based instruction have higher scientific reasoning than students taught through the subject matter approach.

Liao and She (2009) examined the impacts of the Scientific Concept Construction and Reconstruction (SCCR) digital learning system on eighth grade students' concept construction, conceptual change, and scientific reasoning involving the topic of "atoms". A two-factorial experimental design was carried out to investigate the effects of the approach of instruction and students' level of scientific reasoning on their pre-, post-, and retention-Atomic Achievement Test, Atomic Dependent Reasoning Test, and Scientific Reasoning Test. A total of 211 eighth graders participated in this study, recruited from six average-achievement classes of a middle school in Taiwan. The control group comprising of 100 students received conventional instruction whereas the experimental group comprising of 111 students received an SCCR Web-based instruction. Results indicate that the experimental group significantly outperformed the conventional group on post- and retention-Atomic Achievement Test and Atomic Dependent Reasoning Test scores, and retention-Scientific Reasoning Test scores. Moreover, students with a higher level of scientific reasoning significantly performed better than students with a lower level of scientific reasoning, regardless of their scores on post- and retention-Atomic Achievement Test and Atomic Dependent Reasoning Test. This study successfully demonstrates that the experimental group students outperformed the conventional group students in the domains of concept construction, conceptual change and scientific reasoning. Moreover, students with a higher level of scientific reasoning were more able to successfully change their alternative conceptions.

Fah (2009) investigated logical thinking abilities among form 4 students in the interior division of Sabah in Malaysia. The main aim of the study was to ascertain if there is any significant difference in students' logical thinking abilities based on their gender and science achievement at lower secondary school. Research findings showed that the overall mean of students' logical thinking abilities were low. The mean score in percentage for the subscales (except conservational reasoning) were lower than the overall mean. This research also revealed that up to 98% of the respondents were categorized at the concrete operational stage whereas only 2% were categorized at the transitional stage. Research findings also found that there was no significant difference in the mean of logical thinking abilities (except for conservational reasoning) based on students' gender.

Remigio et al. (2014) examined the effect of reasoning skills of first year high school students in a private Catholic school in Isabela, Region 02 after learning general science concepts through analogies. Two intact heterogeneous classes were randomly assigned to Analogy-Enhanced Instruction (AEI) group and Non Analogy-Enhanced (NAEI) group. A sample of 93 students took part in the study. The AEI group was composed of 46 students while the NAEI group had 47 students. Various analogies were incorporated in the lessons of the AEI group for eight weeks. The group exposed to AEI was expected to have a higher mean score in the Scientific Reasoning Test (SRT). However, no significant difference was found on the posttest mean score of the AEI and NAEI groups. Also, no significant difference was found on the two groups' posttest mean scores in each of the five reasoning skills (conservation of mass and volume, proportional reasoning, identification and control of variables, probabilistic reasoning and correlational reasoning).

Abdullah and Shariff (2008) investigated the effects of inquiry-based computer simulation with cooperative learning on scientific thinking and conceptual understanding of Gas Laws. The main purpose of their study was to investigate the effects of inquiry-based computer simulation with heterogeneous-ability (HACL) and inquiry-based computer simulation with friendship cooperative learning (FCL) on (a) scientific reasoning (SR) and (b) conceptual understanding (CU) among Form Four students in Malaysian Smart Schools. The study further investigated the effects of the HACL and FCL methods on performance in scientific reasoning and conceptual understanding among empirical-inductive (EI) and hypothetical-deductive (HD) students. The sample consisted of 301 Form Four students from 12 pure science classes in four Smart Schools from Kedah and Penang in Malaysia which were all randomly selected and assigned to experimental (HACL and FCL) and control (TG) groups. The results of the study showed that students in the HACL group significantly outperformed their counterparts in the FCL group who, in turn, significantly outperformed their counterparts in the TG group in scientific reasoning and conceptual understanding. The results of the study also found that the HD students in the HACL group significantly outperformed their counterparts in the FCL and TG groups. However, there were no significant differences between the performance of HD students in the FCL group and the TG group in scientific reasoning and conceptual understanding. The results of the study showed that the EI students in the HACL group significantly outperformed their counterparts in the FCL group who, in turn, outperformed their counterparts in the TG group in scientific reasoning and conceptual understanding. Finally, the results should that there was no interaction effect between instructional method and student reasoning ability levels. Based on the findings, the authors recommended that the inquiry-based computer simulation with heterogeneous-ability cooperative learning method is effective in enhancing scientific reasoning and conceptual understanding of students of all reasoning abilities, and for maximum effectiveness, cooperative learning groups should be composed of students of heterogeneous abilities.

Studies on Students' Alternative Conceptions in Electric Circuits and Changes in Conception

Following an extensive review of the research literature, Wandersee, Mintzes, and Novak (1994) generated eight "emerging" research-based claims relating to alternative conceptions in science: 1. Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events. 2. The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries. 3. Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies. 4. Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers. 5. Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture, and language, as well as in teachers' explanations and instructional materials. 6. Teachers often subscribe to the same alternative conceptions as their students. 7. Learners' prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse variety of unintended learning outcomes. 8. Instructional approaches that facilitate conceptual change can be effective classroom tools.

Based on these claims, many researches (Afra, Osta & Zoubeir, 2009, Cepni˙ & Keles, 2005; Engelhardt & Beichner, 2004; İpek & Çalık, 2008; Lee & Law, 2001; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; McDermott & Shaffer 1992) have been done to identify (primary, secondary and university) students' alternative conceptions related simple electric circuits. From those studies, in general, students have the following ideas about simple electric circuits: (a) 'Unipolar model (sink theory)': one wire between a bulb and a battery is enough to light the bulb; (b) 'Clashing Current theory (two-component model)': current leaves from the positive terminal and negative current leaves from the negative terminal of the battery and they meet and produce energy in the bulb; (c) 'Closed circuit model': the circuit elements have two connections. Current circulates around the circuit in a given direction and current flowing through a resistive circuit element liberates energy; (d) 'Current consumption model (Attenuation model)': current travels around the circuit in one direction and the devices in the circuit share the current equally; however less current returns to the power source than originally leaves (i.e., some portion of the current is used up as it goes through each component of the circuits; (e) 'Constant current source model': battery is seen as a source of constant current. The current supplied by the battery is always the same regardless of the circuit features; (f) 'Scientific view': current flows around the circuits transmitting energy. Current is conserved and well differentiated from energy. The circuit is seen in a whole as an interacting system, such that a change introduced at one point of the circuit affects the entire system.

For instance, Mcdermott and Shaffer (1992) investigated how students' understanding of electric circuit has contributed to the building of a research base that can be used to guide the development of curriculum that matches the needs and abilities of students. The subject matter in the research is an electric circuit that consists only of batteries and resistive elements. They found that some serious conceptual and reasoning difficulties were not solved after using standard lecture and laboratory instruction. The difficulties identified were divided into three general categories: inability to apply formal concepts to electric circuits, inability to use and interpret formal representation s of electric circuits, and an inability to reason qualitatively about the behaviour of electric circuits.

Engelhardt and Beichner (2004) have studied students' understanding of direct current resistive electrical circuits. They found that both high school and university students' reasoning patterns regarding direct current resistive electric circuits often differ from the currently accepted explanations. The information provided by the exam provides classroom instructors a means with which to evaluate the progress and conceptual difficulties of their students and their instructional methods. It can be used to evaluate curricular packages or other supplemental materials for their effectiveness in overcoming students' conceptual difficulties. They indicated that students, especially females, tend to hold multiple misconceptions, even after instruction. During interviews, the idea that the battery is a constant source of current was used most often in answering the questions. Students tended to focus on current in solving the problems and to confuse terms, often assigning the properties of current to voltage and/or resistance. Students do not have a clear understanding of the underlying mechanisms of electric circuit phenomena. On the other hand, students were able to translate easily from a "realistic" representation of a circuit to the corresponding schematic diagram.

Cepni˙ and Keles (2005) studied Turkish students' understanding level of electric circuits consisting of two bulbs and one battery was investigated by using open-ended questions. Two-hundred fifty students, whose ages range from 11 to 22, were chosen from five different groups at primary, secondary and university levels in Trabzon in Turkey. In analysing students' drawings and explanations, both qualitative and quantitative methodologies were exploited. The unipolar model (Model A), the clashing currents model (Model B), the current consumed model (Model C) and the scientist model with current conserved (Model D) determined from the related literature were used to categorise the students' answers. The results showed that the Turkish students have many misconceptions about electric circuits. Also, it is found out that especially Model A was widespread accepted among the students in group 1 (5^{th} grade) and half of the students in group 3 (9^{th} grade) has an understanding of electric circuits as it is in Model C.

Küçüközer and Kocakülah (2007) aimed at revealing secondary school students' misconceptions about simple electric circuits. Seventy-six (76) students in the three grade 9 classes in the city of Balikesir in Turkey participated in the study. The results revealed the following misconceptions specific to Turkish students: none of the bulbs will light when the circuit is closed, bulbs in parallel are always brighter than those in series, batteries are constant current sources and current is consumed by circuit components. The sources of such misconceptions were found to emerge from everyday use of language and misconceptions acquired during teaching.

Afra, Osta and Zoubeir (2009) investigated the alternative conceptions that a group of 12 Lebanese students in a grade 9 class hold about electricity. It also attempted to evaluate learning outcomes of implementing in that class an inquiry-based module for the acquisition of conceptual understanding of basic concepts in electricity. The findings revealed that most of the alternative conceptions reported in literature were found amongst the participants. Results of the posttest showed that the implemented inquiry-based approach was successful in enhancing participants - conceptual understanding of the targeted DC circuit concepts.

There is also some evidence to indicate that students change their reasoning pattern to suit the question at hand (Heller & Finley, 1992). Thus, they do not appear to use a single model to analyse circuit phenomena. In analysing circuits, students use one of three ways of reasoning: sequential, local or superposition (Ates, 2005). Students using sequential reasoning believe that current is influenced by each circuit element as it is encountered and a change made at a particular point does not affect the current until it reaches that point (Afra, Osta & Zoubeir, 2009). Local reasoning means that current divides into two equal parts at every junction regardless of what is happening elsewhere (Borges & Gilbert, 1999). Students using superposition reasoning would conclude that if one battery makes a bulb shine with a certain brightness, then two batteries would make the bulb shine twice as bright regardless of the configuration (Sebastia, 1993).

Some aspects of circuits seem to occupy a more central place in students' mental models so that instruction may affect them to different degrees. For example, a student who does not have a proper understanding about the difference between electricity, current, energy, power, voltage and charge is unlikely to use them interchangeably (Ates, 2005; Borges & Gilbert, 1999). However, the correct understanding of main science concepts is not possible by using mathematical equation and formulas in explaining concepts (Frederiksen & White, 2000). Research findings suggest that students can easily change their views about some of the above-mentioned aspects than about others after instruction (Afra, Osta & Zoubeir, 2009). After students are provided a battery, a bulb and some wires and then asked to light the bulb, they recognize that circuit elements are bipolar devices and circuits should be closed if current is to circulate in it (Cosgrove, 1995). However, some aspects of students' mental models of electric circuits are more resistant to change, such as those involving the concept of current and energy (Borges & Gilbert, 1999; McDermott, 1991). This becomes a critical difficulty when students study more complex circuits involving combination of resistors in series and parallel (Borges & Gilbert, 1999) and when they start to learn microscopic process going on in a circuit (Eylon & Ganiel, 1990). Some researchers point out that the problem is with the lack of differentiation between current and energy (Ates, 2005), while others mentioned that problem is with the lack of robust models of understanding microscopic process leading to the macroscopic phenomena observed (Eylon & Ganiel, 1990).

A wide range of pedagogies have been found to address alternative conceptions such as learning cycles (Ates, 2005), an inquiry approach coupled with concept substitution strategies (Harrison, Grayson, & Treagust, 1999), conceptual change texts (Carles & Andre, 1992), computer simulation (Ronen & Eliahu, 2000), analogies (Chiu & Lin, 2005), conflict maps (Tsai, 2003) and inquiry-based approaches (Baser, 2006a; Baser, 2006b; Zacharia, 2007). These approaches tend to have in common the requirement that students encounter phenomena that run counter to their existing beliefs. Doing so, they are put in a state of intellectual disequilibrium or cognitive conflict. Becoming aware of the conflict between what they believe to be correct based on prior experiences and know to be correct based on more recent experience helps them to confront and resolve their conflicting perspectives in favor of a proper understanding. Such pedagogical approaches that emphasise conflict and resolution appear to derive from a Piagetian perspective on learning (Scott, Asoko, & Driver, 1992). In such a viewpoint, the learner's role in reorganizing their knowledge is central to overcoming the alternative conception.

Inquiry-based teaching approaches especially, have been found to be effective for changing students' alternative conceptions since it encourages students to be mentally committed by guiding them through the process of constructing their models with which they can explain behaviours of electric circuits (Zachara, 2007). However, there appear to be no study conducted on the effectiveness of using the combination of inquiry-based real hands-on laboratory and computer simulation methods with cooperative learning in changing students' alternative conception. One of the areas in which this study will contribute to existing body of literature will be the findings obtained in this area.

Inquiry-based science teaching and learning is a constructivist approach which provides a perspective on teaching and learning science in the classroom, with a view to improving the effectiveness of science teaching and other disciplines in enhancing students' learning. It emphasises that knowledge is constructed by an individual through active thinking and that social interaction is necessary to create shared meaning, and so an individual needs to be actively engaged both behaviorally and mentally in the learning process for learning to take place (Cakir, 2008; Fayet al., 2007; Mayer, 2004). Several methods of inquiry-based teaching and learning exist but the 3-E inquiry-based learning cycle model which is based on well-known theoretical frameworks from science education and cognitive psychology theories that emphasis cognitive development and individual interaction with the environment (Piaget, 1952), social interaction (Vygotsky, 1978) and conceptual change (Posner et al., 1982) has been found to be the most effective for promoting meaningful learning and logical thinking necessary to construct concepts and conceptual systems (Bybee, 2004; Lawson, 2001; Musheno & Lawson, 1999).

Inquiry-based learning often incorporates an element of cooperative learning which means the engagement of participants in a common endeavour (Dillenbourg, 1999; Duit & Treagust, 1998). Peer interaction in inquiry-based learning promotes cognitive processing (Hoy et al., 2002; King, 2002) by supporting students to draw conclusions from the results of an inquiry (Slavin, 1996; Johnson & Johnson, 1999; Morgan & Keitz, 2010). Peer collaboration also offers three cognitive benefits: articulation, conflict, and co-construction (Crook, 1994). Researches (Thanh & Gillies, 2010; van der Laan Smith & Spindle, 2007;

Watson & Marshall, 1995) have shown that there are three main ways by which cooperative learning groups can be found namely "heterogeneous", "homogeneous" and "friendship groupings. Homogeneous grouping should be discouraged since it undermines democratic values and contributes to a stratified society or segregation (Morgan & Keitz, 2010; Slavin &Braddock, 1993). Empirical-inductive students in homogeneous grouping are prone to absenteeism, drop out, social problems, and are less likely to go to college since they miss out on dialogue with hypothetical-deductive peers that have a better understanding of the material and are able to elaborate and explain it more effectively to them (Heath, 1999; Poole, 2008; Slavin, 1993).

The review of related literature brought to fore that inquiry-based hands-on laboratory activities and inquiry-based computer simulation activities or methods have been considered as competing and mutually exclusive methods in science teaching and learning. However, research on the comparison of the two methods have yielded mixed results. A growing numbers of researches are advocating for the combination of real hands-on laboratory and computer simulation activities instead of comparing the two learning environments (Ainsworth, 2006; Jaakkola et al., 2011; Ronen & Eliahu, 2000; Zacharia, 2007; Zacharia et al., 2008).

Although a number of researches have been conducted on the use of the combination of inquiry-based real hands-on laboratory and computer simulation methods in teaching scientific concepts, it appears all the studies in literature only compared the combination of inquiry-based real hands-on laboratory and computer simulation activities to inquiry-based real hands-on laboratory activities only and/or inquiry-based computer simulation activities only. In all this studies, the results showed that in almost all of the studies, the group which had the combinational activities outperformed their counterparts in the other groups. There appear to be a methodological floor in such conclusions. The reason is that the combinational group in all the studies had an advantage over the other groups in terms of double representation of teaching and time of instruction. This study is therefore sought to fill in this gap in literature where students in all groups will be given equal opportunities in terms of number of representations and time of instruction.

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, scientific reasoning and change in conceptions. 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 (Abdullah & Shariff, 2008; Lou et al., 1996). 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.

CHAPTER THREE

RESEARCH METHODS

This chapter describes and explains how the study was conducted. It discusses the research design, population, sample and sampling procedure, instrument, data collection and data analysis.

Research Design

The first 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' conceptual understanding of electric circuits and scientific reasoning levels when the students are organised in two types of cooperative learning groupings (i.e., HACL and FCL groupings). Secondly, students in each of the two groupings were compared on the basis of the changes in their conceptions in electric circuit. Based on these aims, the study adopted a quasi-experimental design (i.e., specifically, the pretest-posttest-delayed posttest non-equivalent groups treatment design) (Cohen, Manion, & Morrison, 2007; Creswell, 2012; Tuckman, 1999).

This design is used most often in educational research where there is no random assignment of students to groups (i.e., intact classes in their natural settings are used) (Cohen & Manion, 1994; Creswell, 2012). In a typical school situation, time tabling cannot be disrupted nor classes reorganised in order to accommodate the researcher's study and in such a situation, it is necessary to use classes which are already organised by the school without the researcher selecting a section of the students for the study (Ary, Jacobs & Razavieh, 1990; Creswell, 2008). 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, what changed 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).

The main weakness of this design is that it is inferior to randomized experiments in terms of internal validity (Trochim, 2000). This study was affected by this weakness since extraneous variables such as age, maturation and previous learning experiences could not be controlled. Another weakness of the design, which is also a threat to internal validity, is the interaction between the HACL group and the FCL group especially when both groups were in the same school. However, this weakness was minimized in the study since both groups were in different schools which are in terms of geographical location far apart (about 20 km apart). The students in both schools were boarders with no 'day' students. This made interaction between the two groups very difficult.

Students in both the HACL group and the FCL group covered the same content of the concepts in electric circuits. Students in both groups took a pretest to measure their prior knowledge of the concepts in electric circuits before instruction, a posttest after instruction to determine students' academic achievements regarding the strategies used, and a delayed posttest to measure the extent to which the content learned could be sustained. In all, six lesson plans were developed for teaching the two groups. Both the HACL and the FCL groups received the same sets of lessons but the difference lies on in the mode of cooperative learning group compositions. One month after the teaching intervention, the delayed posttest was administered to see how the interventions had helped students to conceptualise or sustain the concepts learned. The research design can be depicted in the visual mode as:

HACL group	N	O_1	X+	O_2	O_3
FCL group	N	O_1	X-	O_2	O_3

where:

N = Non-equivalent

O_1 = Pretest measure

O_2 = Posttest measure

O_3 = Delayed posttest measure

X+ = Combination of inquiry-based real hands-on laboratory and computer simulation methods with HACL grouping.

X- = Combination of inquiry-based real hands-on laboratory and computer simulation methods with FCL grouping.

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 with 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 and students' scientific reasoning ability. The first dependent variable (i.e., conceptual understanding - CU) – is the degree to which what students understand regarding electric circuits corresponds to the scientifically accepted explanations of concepts in electric circuits. The second dependent variable (i.e., scientific reasoning ability - SR) – is the quality of thought that students were able to produce using hypothesis and deduction in their reasoning. 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 (Gay & Airasian, 2003; Slavin, 1996). The factorial design of the study is illustrated in Figure 2.

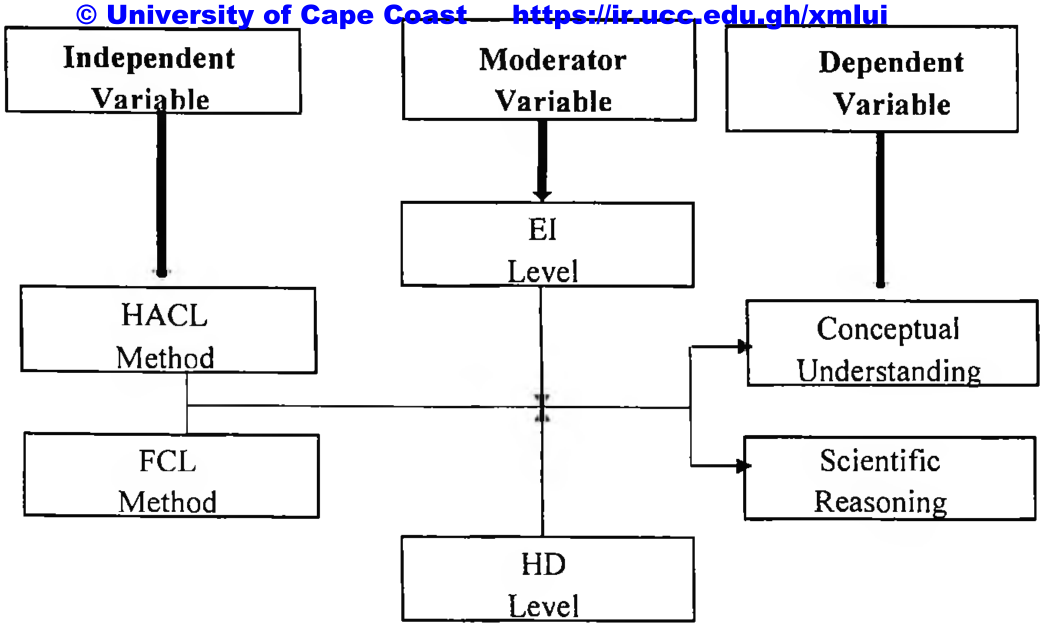

Figure 2: Factorial design of the study.

Again, this quasi-experimental design used both quantitative and qualitative methodologies to collect data in this study. The first part of the study dealt with comparing the achievements of the HACL and the FCL groups and also the achievement of the HD and EI students in both groups in conceptual understanding and scientific reasoning. These employed quantitative approaches of data collection. The second part of this study sought to find out how students' conception changed from pretest to posttest. This requires an in-depth analysis of students' responses qualitatively.

Population

The target population was Form 2 students from the 10 public Senior High Schools (SHS) offering all the four elective science subjects (physics, chemistry, biology and mathematics) in the Cape Coast metropolis in the 2012/2013 academic year. Only Form 2 students were used because electric circuit which is a sub-concept under the main topic 'Direct Current Circuit Analysis' is taught in the second term of the second year as depicted in the teaching syllabus for elective physics syllabus (Ministry of Education, 2010).

Sampling Procedure

The sample consisted of 110 Form 2 students in two intact classes selected from two different SHS in the Cape Coast Metropolis. The average age of the students in the two classes used was 16.5 year old [see APPENDIX A for average age of students in the HACL and FCL groups]. Computer generated random numbers were 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 from the 10 senior high schools 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 (Hair, Anderson, Tatham, & Black, 1998).

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 pretest. 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 (Lou et al., 1996). 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 (see APPENDIX B for distribution of scores for GALT).

Data Collection Instruments

The study used three main instruments for data collection. The first instrument used was an achievement test called Current Electricity Concepts Achievement Test (CECAT) developed by Aboagye, Ossei-Anto and Johnson (2011) 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, posttest and delayed posttest (see APPENDIX C for CECAT). It consists of thirty (30) 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 shown in Table 1.

Table 1

Instructional Objectives for Current Electricity Concepts Achievement Test (CECAT) and Question Numbers

Instructional Objectives	Question Numbers
Physical aspects of electric circuits	
1. Identify and explain a short circuit (i.e., more current flows through the path of lesser resistance).	13, 24
2. Explain the functional two-endedness of circuit elements (i.e., circuit elements have two possible points with which to make a connection).	18

Table 1, continued

3. Identify a complete circuit and acknowledge the necessity of a complete circuit for charges to flow in a steady state.	28
4. Apply the concept of resistance to a variety of circuits.	5, 9, 10
5. Interpret diagrams for a variety of circuits including series, parallel and combination of the two.	6, 17, 19
6. Apply the conceptual understanding that the battery is a source of electrical energy.	7
Current	
7. Apply the conservation of current to a variety of circuits.	3, 12
8. Explain the microscopic aspects of charge flow in a circuit.	1, 2, 22, 30
Potential difference	
9. Apply the knowledge that the amount of current is influenced by the potential difference maintained by the battery and resistance in a circuit.	4, 8, 11
10. Apply the concept of potential difference to a variety of circuits including the knowledge that total potential difference in a series circuit is the sum of all the individual potential differences whiles in a parallel circuit the total potential difference is equal everywhere in the circuit.	14, 15, 16 20, 21, 23, 25
Current and Voltage	
11. Combine the concepts of current and potential difference to a variety of circuits.	26, 27, 29

The second instrument was a conceptual change test called Electric Circuit Conception Test (ECCT) developed by the researcher based on students' alternative conceptions in electric circuits obtained from extensive review of related literature. ECCT was used to determine students' alternative conceptions during the pretest and the extent to which students changed their conception during the posttest. It comprised initially of twelve two-tier items but was reduced to nine items after pilot testing. The choice of an option demands an explanation or reasoning. This is because, it was important for this study to be supported by qualitative reasons students base their answers upon because scientifically valid causal reasoning which supports an answer is an indication of deep understanding of the concept (Lee & Law, 2001). Grotzer and Perkins (2000) refer to and acknowledge "a paucity of causal models in students' understanding" (p. 1) and "shallow explanations" (p. 3) which students usually offer when understanding in science is probed. Thus, only by dealing with students' reasons for their answers could the probing of ideas lead to some indication of students' ideas and their understanding.

The explanations were not scored dichotomously (i.e., scientifically correct or incorrect). A correct option chosen and a correct explanation was awarded 2 marks, a correct option chosen and wrong explanation was awarded 0 because it meant the student guessed, while a wrong option and correct explanation was awarded 1 mark. Simply put, 1 mark was for correct option and another 1 mark was for correct explanation (See APPENDIX D for ECCT). The difference between CECAT and ECCT is that items in CECAT tested how students can apply all the concepts in electric circuits as shown in Table 1 while items in ECCT focused on alternative conceptions as reported in the various literature reviewed. Items in ECCT require students to provide explanations to any option they choose which was not the case in CECAT.

The third instrument was the Group Assessment of Logical Thinking Test (GALT) developed by Roadrangka, Yeany, and Padilla (1983) to measure students' level of reasoning abilities under the following subscales: conservational reasoning, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. The distribution of items according to the six different levels of reasoning abilities is shown in Table 2. GALT was adapted (i.e., some of the items [1, 2, 5, 8, 9, 10 and 11] were rephrased to suit the Ghanaian context) 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).

Table 2

Distribution of Items According to the Six Different Levels of Reasoning Abilities

Subscales	Item	No. of Items
Conservational reasoning	1, 2	2
Proportional reasoning	3, 4	2
Controlling variables	5, 6	2
Probabilistic reasoning	7, 8	2
Correlational reasoning	9, 10	2
Combinatorial reasoning	11, 12	2
Total		12

The advantage of GALT over the other instruments is that it uses simple and clear language for students at all levels to understand without problems (Fah, 2009). GALT consists of 12 items which uses a double multiple choice response format for presenting options for answers as well as the justification or reason for that answer. Pictorial representations of real objects are also employed in the test items to enhance better understanding of the items (see APPENDIX E for GALT). 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.

Validity

Content validity of the instruments was established by presenting the tests and its instructional objectives (IOs) to two physics lecturers in the Department of Science and Mathematics Education and the researcher's team of supervisors for inspection to ensure that the domains are adequately covered.

The six lesson plans that were developed for teaching the selected concepts in electric circuits were shown to the team of supervisors and two Science Education physics lecturers for their appraisal. The six lessons were then field tested by the researcher in collaboration with three other physics teachers. These enabled further modifications to be made to obtain the final form for the main study.

Pilot testing

After all the instruments have been modified upon expert advice, they were field tested. The tests were administered to Form 4 students offering elective physics in two of the senior high schools in the Cape Coast Municipality in order to determine its reliability and validity. Form 4 students were chosen because they had already been taught concepts in electric circuits in Form 2 and were in a better position to answer the questions. The Form 3 students were not used though they had also treated concepts in electric circuits because at the time of pilot testing, they were preparing seriously for their final examinations which they will be writing with the Form 4 students. Based on this, the school authorities asked that only the Form 4 students be used.

Reliability

One hundred and twenty-five Form 4 students took part in CECAT and it took them approximately one hour to complete it. Students' total scores for the items ranged from 0 to 30 out of 30 items. The reliability of the test was calculated using the KR-20 formula and the coefficient found to be .77. The discrimination and difficulty indices of the items were also determined to further check the validity of the items. The average difficulty and discrimination indices of CECAT were .49 and .47 respectively (see APPENDIX F for the answers, discrimination and difficulty indices of the items in CECAT).

One hundred and twelve Form 4 students took part in ECCT and the time allowed was one hour. Students' scores ranged from 0 to 18 of 9 two-tier items. The reliability coefficient calculated using Cronbach alpha was found to be .73 (see APPENDIX G for SPSS output of Cronbach alpha reliability coefficient of the items in ECCT). Cronbach alpha was used because the award of scores was at three levels (i.e., a correct option chosen and a corresponding correct explanation was awarded 2 marks; a correct option chosen and wrong explanation was awarded 0; and a wrong option and correct explanation was awarded 1 mark). Both the question papers and the answer sheets for CECAT and ECCT were collected from the students just after the test.

Seventy-six Form 4 students took part in GALT and the time allowed for the test was one hour. Students' total score ranged from 0 to 12 of 12 two-tier items. The reliability calculated using KR-20 gave a coefficient of .71. Difficulty and discrimination indices of the items in GALT were also calculated and the average difficulty and discrimination indices of GALT were .54 and .61 respectively (see APPENDIX H for the discrimination and difficulty indices of the items in GALT). The items were answered on the question paper and all were collected just after the test.

Data Collection Procedures

Permission was sought from the headmasters and the physics teachers of the two schools to allow me use the classes concerned for the study. Permission was granted and the students were informed of the intended study. Training programmes were organised for the two physics teachers whose classes were used for the study on the use of the combination of inquiry-based real hands-on and computer simulation methods lesson plans.

The researcher in collaboration with the physics teachers in the two classes administered CECAT, ECCT and GALT as pretest to the HACL and FCL groups to assess students' knowledge on concepts in electric circuits and their scientific reasoning skills prior to the interventions. The HACL group was instructed using the HACL grouping method while the FCL group was instructed using the FCL grouping method by the researcher with the help of the permanent physics teacher of the classes used. Students in the HACL group were assigned to a four or five member heterogeneous-ability groupings by the researcher. This heterogeneous-ability grouping were formed based on students' scores in GALT. 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 (Lou et al., 1996). After pretesting GALT, there were 21 HD students and 34 EI students in the HACL group. 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 assigned to four or five-member cooperative groups by having them choose members of their class with whom they most preferred or desired to work together. A careful examination of the groups formed by the FCL group from the scores obtained by the individual students 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.

At the time the study was undertaken, the Form 2 students had not yet been taught direct current circuit analysis and so the students gave the researcher the fullest cooperation because they would not be taught the topic again before they write their final examinations. In order not to inconvenient the class teachers and the students used, after data collection, the researcher continued to teach the rest of the concepts under direct current circuit analysis.

Instruction with instructional materials

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 in this study is called Circuit Construction Kit (CCK) developed by Physics Education Technology (PhET), University of Colorado at Boulder and a sample is shown in Figure 3.

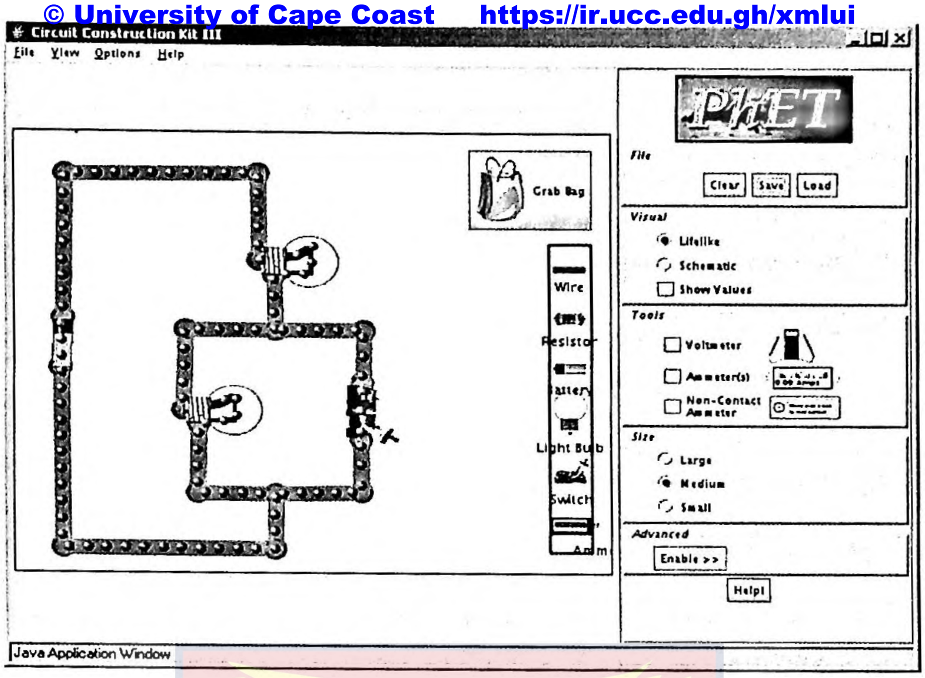

Figure 3: Part of the Circuit Construction Kit (CCK) package interface for windows

Permission was sought online from the University of Colorado and the software was made available to the researcher. The students were given step by step instructions on how to use CCK and asked to explore the different parts of the simulation. A set of controls in Control Bar Region provided the students with the ability to vary the input parameters for the simulation. Students had to decide which variables to vary and which to keep constant before running the simulation and to make necessary observations. Each group of students then performed a set of experiments using prescribed instructions provided on electric circuits.

Description of the inquiry-based model used

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 as follows:

1. Exploration: This phase typically consisted of hands-on activities or field experience in which students gathered and recorded data from their observations and measurements. The purpose of this phase is that students are encouraged to learn through their own experience. At the start of each lesson session, the researcher and the physics teacher explained the specific requirement and procedure for the learning tasks. During each practical activity lesson, a set of materials were provided for students in their groups to perform the experimental tasks. Every student was given an activity sheet containing instructions to be followed. On this sheet, spaces were provided for students to write their predictions before performing a specific task, then make observation and draw conclusions after each activity. When their predictions and observations are inconsistent with each other, the students' explanations were explored within their groups and to other groups. This helped students to reconcile their prior ideas with their current observations. Students in their groups performed the activities first with computer simulations followed by real hands-on activities.
2. Explanation: Only after the students had thoroughly investigated, discussed and attempted to logically explain the phenomena they encountered during the exploration stage, the researcher took an active role and offered the students a more in-depth or scientifically accepted explanation and further explained new terms that emerged. Students used their experience from exploration phase to develop an understanding of the emerging electric circuit concepts with guidance from the researcher and teacher.
3. Expansion: The researcher then posed new situations or problems which can be solved directly by applying concepts learned in the previous exploration

experiences and explanation phase. Students were also given further experiments or investigations to perform in their groups in order to reinforce understanding.

The concepts to be taught include the following: 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. The six lesson plans for teaching the selected concepts in electric circuits using combination of inquiry-based real hands-on laboratory and computer simulation methods were presented in APPENDIX I.

Two days after the end of the teaching session six in each school, the entire classes in all group conditions were given CECAT, ECCT and GALT as posttest to determine their understanding, conceptions and scientific reasoning respectively. One month after the posttest, CECAT and GALT were given as delayed posttests to the students to determine if the concepts have been well consolidated and retained. This was done to show appreciation for the time given to the researcher for his study. The entire period of data collection lasted for 11 weeks. The first week was used for pre-testing of the various instruments, six weeks was used to administer the six teaching session (i.e., 120 minutes per week) and the last week was used to administer the delayed posttest.

Data Processing and Analysis

Null hypotheses one, three and four were tested using a two-way multivariate analysis of variance (MANOVA). MONOVA was used because there were two factors (i.e., dependent and independent variables) each of which were at two levels. The two levels of the dependent variable, students' learning outcomes, were: (a) scores for scientific reasoning obtained from GALT; and (b) scores for conceptual understanding of electric circuits obtained from CECAT while the two levels of the independent variable (i.e., the method of grouping) were HACL group and FCL group. MANOVA was therefore used to avoid type 1 error since there were two dependent variables in this study. To measure the interaction effects between instructional methods and students' scientific reasoning levels for scientific reasoning and conceptual understanding of electric circuits, a two-way multivariate analysis of covariance (MANCOVA) was used.

Null hypotheses two, five and six were tested using the McNemar chi square test for significance of change. McNemar Chi-Square test for significance of change was used because it has the ability to determine the degree of changes in students' conceptions from pretest to posttest (see APPENDIX J for description of McNemar chi-square and Chi-Square Distribution Table).

CHAPTER FOUR

RESULTS AND DISCUSSION

In this chapter, the results of the study are presented and discussed in relation to the seven hypotheses that were tested. All hypotheses were tested at .05 level of significance.

Pre-Experimental Study Results

Pre-experimental screening was done to test the assumptions that the samples across the HACL and FCL groups were equivalent in their scientific reasoning and conceptual understanding of electric circuits. To fulfil this purpose, preliminary analyses were done by comparing the two groups' pretest mean scores using a multiple analysis of variance (MANOVA). Preliminary assumption testing was also conducted to check for normality, linearity and multicollinearity, multivariate outliers and multivariate normality, homogeneity of covariance matrices and test of equality of error variance. It was observed that there were no violations [see APPENDIX K for SPSS output for assumption testing of pretest].

Table 3 summaries the descriptive statistics for the dependent variables (i.e., scores of pre-conceptual understanding [Pre-CU] and scores of pre-scientific reasoning [Pre-SR]) for the two groups. As shown in Table 3, the two groups had relatively similar mean scores in pre-CU: 12.95 and 12.76 for HACL group and FCL group respectively. The mean scores of the two groups were also relatively similar in pre-SR: 5.35 and 5.42 for HACL group and FCL group respectively.

Table 3

Means and Standard Deviations for Pre-CU and Pre-SR by Groups

Dependent Variable		HACL (N = 55)	FCL (N = 55)
Pre-CU	Mean	12.95	12.76
	SD	3.50	2.71
Pre-SR	Mean	5.35	5.42
	SD	1.97	2.01

Note: Total score for pre-SR = 12, and total score for pre-CU = 30

To examine if there were statistically significant difference in mean scores between students in the two groups with respect to pre-SR and pre- CU, MANOVA was conducted. Table 4 presents the summary of multiple analysis of variance results of pre-SR and pre-CU of electric circuits for pretest. According to Field (2006) and Tabachnick and Fidell (2013), in the evaluation of the multivariate differences, Pillai's Trace criterion was considered to have the acceptable power and to be the most robust statistic against violations of assumptions [i.e., it offers protection against Type I errors with small sample sizes].

Table 4

Summary of MANOVA Effect on Pre-SR and Pre-CU of Electric Circuits

Dependent Variables	Multivariate F	Pillai's Trace	df	p
Pre-SR Pre-CU	.068	.001	2, 107	.935

Not significant, since $p > .05$

As shown in Table 4, there was no statistically significant difference in mean scores between HACL and FCL groups on the combined dependent variables: $F(2, 107) = .068$, $p = .935$, *Pillai's Trace* = .001. The results in Table 4 indicate that on the average, students in both groups had similar levels of scientific reasoning and similar preconceptions of electric circuits and that they had started the treatments with nearly the same level of reasoning and learning. This confirms the Levene's test of equality of error variance which indicated that the groups were equivalent at pre-SR [$F(1, 108)$, $p = .915$] and pre-CU [$F(1, 108)$, $p = .028$] determined using the Bonferroni adjusted alpha level of .025. Furthermore, a post hoc power analysis was conducted using the Gpower software to check whether the non-statistically significant results obtained in scientific reasoning and conceptual understanding between the two groups' mean scores were due to lack of statistical power of MANOVA. The results revealed that the power of the test $(1 - \beta) = .058$, which implies that the probability of finding a true significant difference in mean scores between the two groups is minimal (i.e., about 6%).

Pre-experimental analyses was done to test the assumptions that the HD students in HACL and FCL groups were equivalent in their scientific reasoning and conceptual understanding of electric circuits. To achieve this aim, preliminary analyses were done by comparing the two groups' pretest mean scores using MANOVA for scientific reasoning and conceptual understanding of electric circuits.

Table 5 summaries the descriptive statistics for the dependent variables (i.e., pre-CU and pre-SR) for the HD students by groups. As shown in Table 5, the two groups had relatively similar mean scores in pre-SR: 7.33 and 7.39 for HACL group and FCL group respectively. The mean scores of the two groups were also relatively similar in pre-CU: 15.81 and 14.52 for HACL group and FCL group respectively.

Table 5

Means and Standard Deviations for Pre-SR and Pre-CU for HD students by Groups

Dependent Variable		HACL (N=21)	FCL (N=23)
Pre-SR	Mean	7.33	7.39
	SD	.66	.58
Pre-CU	Mean	15.81	14.52
	SD	2.82	2.50

Note: Total score for pre-SR = 12, and total score for pre-CU = 30

To investigate if there was statistically significant difference in mean scores between HD students in the two groups with respect to pre-SR and pre-CU, MANOVA was conducted. Table 6 presents the summary of multiple analysis of variance results of pre-SR and pre-CU of electric circuits for pretest. The Pillai's Trace was used to evaluate the multivariate difference.

Table 6

Summary of MANOVA Effect for HD Students in Pre-SR and Pre-CU of Electric Circuits

Dependent Variables	Multivariate F	Pillai's Trace	df	p
Pre-SR				
	1.352	.062	2, 41	.270
Pre-CU				

Not significant, since $p > .05$

As shown in Table 6, the HD students in the HACL and FCL groups are equivalent in scientific reasoning and conceptual understanding of electric circuits on the combined dependent variables: $F(2, 41) = 1, 352$, $p = .270$, *Pillai's Trace* = .062. This means that there was no statistically significant difference between HD students in HACL and FCL groups for pre-SR and pre-CU (i.e., before treatment).

Pre-experimental analyses was done to test the assumptions that the EI students in HACL and FCL groups were equivalent in their scientific reasoning and conceptual understanding of electric circuits. To achieve this purpose, preliminary analyses were done by comparing the two groups' pretest mean scores using MANOVA for scientific reasoning and conceptual understanding of electric circuits.

Table 7 summaries the descriptive statistics for the dependent variables (pre-CU and pre-SR) for the EI students by groups.

Table 7

Means and Standard Deviations for Pre-SR and Pre-CU for EI Students by Groups

Dependent Variable		HACL (N=34)	FCL (N=32)
Pre-SR	Mean	3.94	4.00
	SD	1.25	1.34
Pre-CU	Mean	10.85	11.94
	SD	2.80	2.00

Note: Total score for pre-SR = 12, and total score for pre-CU = 30

As shown in Table 7, the two groups had relatively similar mean scores in pre-SR: 3.94 and 4.00 for HACL group and FCL group respectively. The mean scores of the two groups were however, relatively different in pre-CU: 10.85 and 11.94 for HACL group and FCL group respectively with the mean score of the FCL group being slightly higher.

Table 8 shows the summary of MANOVA results of EI students' pretest mean scores in scientific reasoning and conceptual understanding of electric circuits. The Pillai's Trace was used to evaluate the MANOVA differences.

Table 8

Summary of MANOVA Effect for EI Students in Pre-SR and Pre-CU of Electric Circuits

Dependent Variables	Multivariate F	Pillai's Trace	df	p
Pre-SR				
	1.599	.048	2, 63	.210
Pre-CU				

Not significant, since $p > .05$

As shown in Table 8, the EI students in the HACL and FCL groups are equivalent in scientific reasoning and conceptual understanding of electric circuits on the combined dependent variables: $F(2, 63) = 1.599$, $p = .21$. This means that there were no statistically significant differences in scientific reasoning and conceptual understanding of electric circuits between EI students in HACL and FCL groups for pre-SR and pre-CU (i.e., before treatment).

Students in the HACL group and the FCL group both completed a ten-item Group Cohesiveness Questionnaire (Kowler, 2009) to determine whether the groups in which students worked were perceived to be cohesive [See Appendix I for Group Cohesiveness Questionnaire]. In all, the members in the HACL group

($M = 4.09$, $SD = .525$) and the FCL group ($M = 4.23$, $SD = .324$) were found to be highly cohesive on a five-point Likert scale [See APPENDIX L for Group Cohesiveness Questionnaire and SPSS Output Data].

Comparison of Posttest Mean Scores in Scientific Reasoning and Conceptual Understanding of Electric circuits between HACL and FCL Groups

Hypothesis one sought to test whether there was no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between senior high school 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. Since there were no statistically significant differences in the two groups' mean scores in pre-SR and pre-CU at the pre-experimental results, 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. It was observed that there were no violations [see APPENDIX M for SPSS output for assumption testing of posttest].

Table 9 presents the descriptive statistics for each dependent variable by groups. As shown in Table 9, the two groups had relatively similar mean scores in post-SR: 6.19 and 6.13 for HACL group and FCL group respectively. However, the mean scores of the two groups were relatively different in post-CU: 20.65 and 17.13 for HACL group and FCL group respectively with the means score of HACL group being higher.

Table 9

Means and Standard Deviations for Post-SR and Post-CU by Groups

Dependent Variable		HACL (N=54)	FCL (N=52)
Post-SR	Mean	6.19	6.13
	SD	2.23	1.77
Post-CU	Mean	20.65	17.13
	SD	3.26	3.40

Note: Total score for post-SR = 12, and total score for post-CU = 30

Table 10 shows the summary of MANOVA results on scientific reasoning and conceptual understanding of electric circuits for posttest. The Pillai's Trace was used to evaluate the MANOVA differences.

Table 10

Summary of MANOVA Effect on Post-SR and Post-CU of Electric Circuits

Dependent Variables	Multivariate F	Pillai's Trace	df	p	Partial Eta Squared
Post-SR Post-CU	14.626	.221	2, 103	.001	.22

*Significant, since $p < .05$

As shown in Table 10, there was a statistically significant difference in mean scores between HACL and FCL groups on the combined dependent variables: $F(2, 103) = 14.63$, $p < .001$, *Pillai's Trace* = .78, *partial eta squared* = .22. 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. A post hoc power analysis using Gpower software also showed that at a critical $F(2, 103)$, the power of the test $(1 - \beta) = .9995$, which means that the probability of finding a true significance as indicated above in MANOVA is about 100%.

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 11, indicate that the only difference in mean scores to reach statistical significance, using the Bonferroni adjusted alpha level of .025, was conceptual understanding: $F(1, 104) = 29.51$, $p < .001$. This means that the instructional method had a main effect on students' conceptual understanding of electric circuits. This effect accounted for 22% of the variance in conceptual understanding [partial eta squared = .22].

Table 11

Summary of the follow-up analysis of variance (ANOVA) results on Post-SR and Post-CU

Dependent variable	Univariate F	df	p	Partial Eta Squared
Post-SR	.017	1, 104	.900	
Post-CU	29.510	1, 104	.001*	.221

*Significant, since $p < .05$

According to Tabachnick and Fidell (2013), to interpret the strength of partial eta squared (effect size statistics) values the following guidelines should be used: a value of .01 and below means a small effect, a value of .06 means moderate effect, and a value of .14 and above means large effect. There was however, no statistically significant difference in mean scores for scientific reasoning: $F(1, 104) = .017$, $p = .90$. An inspection of the mean scores as presented in Table 9 and the results of ANOVA as shown in Table 11 indicates 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. On the other hand, the mean scores as shown Table 9 and the results of ANOVA as shown in Table 11 indicate that there was no statistically significant difference in mean scores between the HACL group (M = 6.19, SD = 2.23) and the FCL group in scientific reasoning (M = 6.13, SD = 1.77).

Again, since there was no statistically significant difference between the HACL and FCL groups' mean scores in pretest for scientific reasoning and conceptual understanding of electric circuits, the pretest and posttest scores for each group were compared using the t-test for dependent samples. The t-test for dependent samples was used because the pretest and posttest scores from the same group of individual are being compared. Results of t-test for dependent samples for pretest and posttest scores of the two groups for scientific reasoning and conceptual understanding of electric circuits is presented in Table 12. As shown in Table 12, there was a statistically significant difference between the two groups' pretest and posttest scores. The HACL group's mean score in scientific reasoning from posttest (M = 6.19, SD = 2.23) was significantly higher than their mean score from the pretest (M = 5.37, SD = 1.98, $t(53)$ = 2.092, p = .041). The magnitude of the difference in mean scores for the HACL group was large with a standardised effect size index of .28. This means the HACL method accounted for 28% of the variance in scientific reasoning. Also, as shown in Table 12, the FCL group's mean score in scientific reasoning from posttest (M = 6.13, SD = 1.77) was significantly higher than their mean score from the pretest (M = 5.42, SD = 2.04, $t(51)$ = 2.040, p = .047). The magnitude of the difference in mean scores for the FCL group was also large with a standardised effect size index of .28. This means the FCL method accounted for 28% of the variance in scientific reasoning [see APPENDIX N for calculation of effect size statistics in scientific reasoning for HACL and FCL groups].

Table 12

Results of t-test for Dependent Samples for Pretest and Posttest Score of HACL and FCL Groups for SR and CU of Electric Circuits

Group	Variable	N	M	SD	t	df	p
HACL (SR)	Pretest	54	5.37	1.98	2.092	53	.041*
	Posttest	54	6.19	2.23			
FCL (SR)	Pretest	52	5.43	2.04	2.040	52	.047*
	Posttest	52	6.13	1.77			
HACL (CU)	Pretest	54	12.98	3.52	12.780	53	.001*
	Posttest	54	20.65	3.26			
FCL (CU)	Pretest	53	12.85	2.72	7.195	52	.001*
	Posttest	53	17.15	3.37			

*significant, since $p < .05$

Again, as shown in Table 12, the HACL group's mean score in conceptual understanding of electric circuits from posttest (M = 20.65, SD = 3.26) was significantly higher than their mean score from the pretest (M = 12.98, SD = 3.52,

$t(53) = 12.780$, $p < .001$). The difference in mean score for the HACL group was large with a standardised effect size index of 1.78. Also, the FCL group's mean scores in conceptual understanding of electric circuits from posttest ($M = 17.15$, $SD = 3.37$) was significantly higher than their mean score from the pretest ($M = 12.85$, $SD = 2.72$, $t(52) = 7.195$, $p < .001$). The difference in mean scores for the FCL group was large with a standardised effect size index of .99 [see APPENDIX N for calculation of effect size statistics in conceptual understanding for HACL and FCL groups].

This means that both the HACL method and the FCL method had a significant effect on students' scientific reasoning and conceptual understanding of electric circuits. This finding from the study is consistent with the argument by Baser (2006a) who claimed that any form of inquiry-based teaching is effective for improving students' understanding of concepts in electric circuits. It also confirms the study of Farrokhnia and Esmailpour (2010), Jaakkola and Nurmi (2008), Jaakkola, Nurmi and Veermans (2011), and Zacharia (2007) that combination of inquiry-based simulation and real laboratory methods in cooperative learning environment leads to conceptual understanding and scientific reasoning. This could be due to the fact that students could interact 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 (Jaakkola et al., 2011).

Additional analysis was done to analyse the two groups' posttest mean scores from CECAT for the eleven instructional objectives (IOs) to determine how effective the different concepts and interrelated concepts in electric circuits were taught in the HACL and FCL groups. Table 13 shows the statistics of posttest mean scores in the instructional objectives for the two groups.

Table 13

Statistics of Posttest Mean Scores in the Instructional Objectives (IOs) for the HACL and FCL Groups

Instructional Objectives (IOs)	Group	Mean	SD	t	p
IO 1 (2 items)	HACL	1.24	.61	.889	.376
	FCL	1.13	.65		
IO 2 (1 item)	HACL	.56	.50	1.860	.066
	FCL	.38	.49		
IO 3 (1 item)	HACL	.87	.34	.316	.754
	FCL	.85	.36		
IO 4 (3 items)	HACL	1.87	.95	2.450	.016*
	FCL	1.43	.89		
IO 5 (3 items)	HACL	2.06	.69	1.578	.117
	FCL	1.81	.90		
IO 6 (1 item)	HACL	.54	.50	2.972	.004*
	FCL	.26	.45		
IO 7 (2 items)	HACL	1.37	.62	3.395	.001*
	FCL	.92	.73		
IO 8 (4 items)	HACL	2.81	.55	6.321	.001*
	FCL	1.94	.61		
	HACL	2.26	.68		

Table 13, continued

IO 9 (3 items)				.492	.624
	FCL	2.32	.61		
	HACL	5.25	1.17		
IO 10 (7 items)				2.262	.026*
	FCL	4.64	1.15		
	HACL	1.96	1.06		
IO 11 (3 items)				2.418	.017*
	FCL	1.49	.95		

*Significant, since $p < .05$

As shown in Table 13, the results revealed that the HACL method was found to be more effective for teaching most of the concepts indicated in the instructional objectives (IOs 4, 6, 7, 8, 10 and 11) compared to the FCL method. On the other hand, results of the analysis revealed that posttest mean scores for the groups on IOs 1, 2, 3, 5 and 9 were not statistically significant.

Further analysis was also done to analyse the two groups' posttest mean scores from GALT for the six different models of logical thinking abilities to determine whether any of the two methods had a significant effect on the logical reasoning of the students in the HACL and FCL groups. Table 14 shows the statistics of posttest mean scores six different models of logical thinking abilities for the HACL and FCL groups.

As shown in Table 14, students in the HACL group outperformed their counterparts in the FCL group in conservational reasoning and proportional reasoning but there were no statistically significant differences in mean scores between the two groups in controlling variables, probabilistic reasoning, correlational reasoning and combinatorial reasoning.

Table 14

Statistics of Posttest Mean Scores Six different Models of Logical Thinking Abilities for the HACL and FCL Groups

Level	Group	M	SD	t	p
Conservational reasoning	HACL	1.37	.65	2.160	.033*
	FCL	1.11	.58		
Proportional reasoning	HACL	.96	.75	2.576	.011*
	FCL	.90	.69		
Controlling variables	HACL	1.11	.75	.660	.511
	FCL	1.02	.72		
Probabilistic reasoning	HACL	1.41	.74	.453	.651
	FCL	1.34	.81		
Correlational reasoning	HACL	.67	.78	1.005	.317
	FCL	.53	.64		
Combinatorial reasoning	HACL	1.72	.42	.055	.956
	FCL	1.72	.53		

*Significant, since $p < .05$

Analysis was also done to examine possible statistically significant differences in delayed posttest mean scores for scientific reasoning and conceptual understanding of electric circuits between the HACL and FCL groups using MANOVA. Table 15 presents the descriptive statistics for each dependent variable by groups. As shown in Table 15, the two groups had relatively similar mean scores in delayed post-SR: 6.85 and 6.63 for HACL group and FCL group respectively.

However, the mean scores of the two groups were relatively different in delayed post-CU: 20.46 and 17.00 for HACL group and FCL group respectively with the means score of HACL group being higher.

Table 15

Means and Standard Deviations for Delayed Post-SR and Delayed Post-CU by Groups

Dependent Variable		HACL (N=54)	FCL (N=52)
Post-SR	Mean	6.85	6.63
	SD	2.35	1.66
Post-CU	Mean	20.46	17.00
	SD	3.13	3.24

Note: Total score for delayed post-SR = 12, and total score for delayed post-CU = 30

The MANOVA showing the difference in mean scores of delay post-SR and delayed post-CU for the HACL and FCL groups are presented in Table 16. The Pillai's Trace was used to evaluate the multivariate difference.

Table 16

Summary of MANOVA Effect on Delayed Post-SR and Delayed Post-CU of Electric Circuits

Dependent Variables	Multivariate F	Pillai's Trace	df	p	Partial Eta Squared
Delayed Post-SR Delayed Post-CU	15.710	.234	2, 103	.000*	.23

*Significant, since $p < .05$

The results of MANOVA showed that there was a statistically significant difference in mean scores between HACL and FCL groups on the combined dependent variables: $F(2, 103) = 15.710$, $p < .001$, *Pillai's Trace* = .234, *partial eta squared* = .23. A post hoc power analysis using Gpower software also showed that at a critical $F(2, 103)$, the power of the test $(1 - \beta) = .9995$, which means that the probability of finding a true significance as indicated above in MANOVA is about 100%.

Furthermore, the results of a follow-up univariate ANOVA tests to check the between-subject effects of the dependent variables on delayed post-SR and delayed post-CU, which is presented in Table 17, indicate that the only difference in mean scores to reach statistical significance, using the Bonferroni adjusted alpha level of .025, was conceptual understanding: $F(1, 104) = 31.423$, $p < .001$, *partial eta squared* = .23. This means that the instructional methods used had a main effect on students' conceptual understanding of electric circuits. This effect accounted for 23% of the variance in conceptual understanding. There was however, no statistically significant difference in mean scores for scientific reasoning: $F(1, 104) = .300$, $p = .585$. An inspection of the mean scores as presented in Table 16 and the results of ANOVA as shown in Table 17 indicates that the HACL group (M = 20.46, SD = 3.13) outperformed their counterparts in the FCL group (M = 17.00, SD = 3.24) in conceptual understanding of electric circuits. On the other hand, the mean scores as shown in Table 16 and the results of ANOVA as shown in Table 17 indicate that there was no statistically significant difference in mean scores between the HACL group (M = 6.85, SD = 2.35) and the FCL group in scientific reasoning (M = 6.63, SD = 1.66).

Table 17

Summary of the follow-up analysis of variance (ANOVA) results on Delayed Post-SR and Delayed Post-CU

Dependent variable	Univariate F	df	p	Partial Eta Squared
Delayed Post-SR	.300	1, 104	.585	
Delayed Post-CU	31.423	1, 104	.001*	.23

*Significant, since $p < .05$

The results in Table 17 suggest that though both methods of instruction showed their potentials of helping students retain their scientific reasoning and conceptual understanding of electric circuits, the HACL grouping method was more superior especially in conceptual understanding than the FCL grouping method.

These findings for hypothesis one support the claim that when students are taught the same concept using two different complementary methods (i.e., combination of inquiry-base real hands-on and computer simulation methods), there is higher possibility that students will retain the concepts for a longer period of time since both methods highlight different aspects of the concept (Ainsworth, 2006; Tabachnek-Schijf & Simon, 1998). Again, making comparisons between two complementary methods can promote conceptual understanding because students focus on the common principles shared by the two methods (Gentner, Loewenstein & Thompson, 2003). This is particularly true when students are made to learn in heterogeneous-ability groups (Ballantine & Larres, 2007; Tieso, 2005).

Based on these statistical results, hypothesis one was partly confirmed and partly rejected. The null hypothesis of no statistically significant difference in performance between the HACL group and the FCL group in (a) scientific reasoning was confirmed and (b) conceptual understanding of electric circuits was rejected. These results confirm partly the findings of Abdullah and Shariff (2008) that students in the HACL group outperformed their counterparts in the FCL group in conceptual understanding of electric circuits but contradicts their findings that students in the HACL group outperformed students in the FCL group in scientific reasoning. The results are also consistent with the theory which holds that giving explanations encourages a student to clarify and reorganise the material to make it understandable to others since the explainer benefits from cognitive restructuring (Salah & De Jong, 2005; Slavin, 1990). This is because HD students in the HACL groups are called upon more to provide leadership and explanations of the material to their EI counterparts through peer interactions and elaborations (Abdullah & Shariff, 2008; Lou, Abrami, & Spense, 2000). Such elaborations could help the HD students who provide the explanation to understand the concepts better by discovering further applications of newly developed concepts, and also providing opportunities for them to become aware of inadequacies or discrepancies in their existing schemas (Piaget, 1952). The EI students on the other hand understood the concepts better because they sought clarification of concepts from their HD counterparts. This to a large extent increased their reasoning abilities toward HD thoughts. This claim supports the meta-analysis study done by Lou, Abrami, and d'Apollonia (2001) which indicates that EI students gained most from being placed in a HD groups because they receive individual guidance and assistance from their more able peers.

Students in the FCL group did not develop a better conceptual understanding of electric circuits compared to their counterparts in the HACL group because there were homogeneous-ability groupings in the FCL group. Based on this, EI students with homogeneous ability grouping in the FCL group might have suffered from a lack of appropriate role models to provide them with explanations and guidance when they needed help (Abdullah & Shariff, 2008). The results also showed that students who worked in both HACL and FCL groups made significantly greater gains in scientific reasoning than they did prior to the interventions. This finding confirms the claims of Fenci (2010), She and Liao (2010), Abdullah and Shariff (2008) and Abdullah and Abbas (2006) who found out that students exposed to inquiry-based teaching especially through computer simulations made significant gains in scientific reasoning and conceptual understanding. This is because computer simulations help students to focus on higher learning processes and also the learning processes can also be controlled by the learners themselves (Edelson et al., 1999; Lehtinen, 2003; van Joolingen et al., 2005).

Comparison of the Degree of Changes in Conception of Electric circuits between the HACL and FCL Groups

Hypothesis two sought to investigate whether there was no statistically significant difference in the degree of changes in conception in electric circuits between senior high school 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.

To test this hypothesis, analysis was done to find out the degree of change of students' alternative conception in electric circuits from pretest to the posttest for the responses provided by the students on Electric Circuits Conception Test (ECCT). The number and percentage of students with alternative conceptions and the type of alternative conception they have in the concepts of electric circuits for both the pretest and posttest were also determined.

To determine the degree of changes in students' alternative conceptions from the pretest to the posttest for each question for the two groups, the McNemar chi square test for significance of changes was used. The degree of changes in students' alternative conception for HACL and FCL groups from the pretest to the posttest for each question was calculated using the McNemar formula and presented in Table 18 [see APPENDIX O for extended version of Table 18].

As shown in Table 18, for Question 1, the percentage of students with alternative conceptions decreased from 56.9% to 7.8% for the HACL group and also decreased from 46.9% to 12.2% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 21.333$ for HACL group and $\chi^2 = 12.190$ for the FCL group). However, as shown in Table 18, for the HACL group, 26(51.0%) students changed their alternative conceptions for the scientifically accepted conception while only 1(2.0%) student developed an alternative conception as a result of the intervention. For the FCL group on the other hand, 19(38.8%) students changed their alternative conceptions for the scientifically accepted conception while 2(4.1%) students developed alternative conceptions as a result of the intervention.

Table 18

Degree of Changes in Students' Alternative Conceptions by Question

	HACL group [N = 51]			FCL group [N = 49]		
Question	Pretest	Posttest	χ^2	Pretest	Posttest	χ^2
1	29(56.9)	4(7.8)	21.333*	23(46.9)	6(12.2)	12.190*
2	25(49.0)	11(21.6)	6.500*	20(40.8)	5(10.2)	10.316*
3	47(92.2)	20(39.2)	23.310*	44(89.8)	27(55.1)	12.190*
4	35(68.6)	16(31.4)	15.429*	28(57.1)	20(40.8)	2.227
5	46(90.2)	35(68.6)	7.692*	48(98.0)	37(75.5)	9.090*
6	44(86.3)	9(18.4)	33.029*	42(85.7)	44(89.8)	1.125
7	47(92.2)	10(20.4)	35.027*	43(87.8)	45(91.8)	1.125
8	38(74.5)	6(11.8)	30.031*	38(77.6)	14(28.6)	17.633*
9	45(88.2)	11(21.6)	32.029*	39(79.6)	23(46.9)	8.036*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

As shown in Table 18, for Question 2, the percentage of students with alternative conceptions decreased from 49.0% to 21.6% for the HACL group and also decreased from 40.8% to 10.2% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 6.500$ for HACL group and $\chi^2 = 11.316$ for the FCL group). However, as shown in Table 18, for the HACL group, 20(39.2%) students changed their alternative conceptions for the scientifically accepted conception while as many as 6(11.8%) students developed alternative conceptions as a result of the intervention.

For the FCL group on the other hand, 17(34.7%) students changed their alternative conceptions for the scientifically accepted conception while 2(4.1%) students developed alternative conceptions as a result of the intervention.

As shown in Table 18, for Question 3, the percentage of students with alternative conceptions decreased from 92.2% to 39.2% for the HACL group and also decreased from 89.8% to 55.1% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 23.310$ for HACL group and $\chi^2 = 12.190$ for the FCL group). However, as shown in Table 18, for the HACL group, 28(54.9%) students changed their alternative conceptions for the scientifically accepted conception while 1(2.0%) student developed alternative conceptions as a result of the intervention. For the FCL group on the other hand, 19(38.8%) students changed their alternative conceptions for the scientifically accepted conception while 2(4.1%) students developed alternative conceptions as a result of the intervention.

As shown in Table 18, for Question 4, the percentage of students with alternative conceptions decreased from 68.6% to 31.4% for the HACL group and also decreased slightly from 57.1% to 40.8% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 15.429$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = 2.227$). However, as shown in Table 18, for the HACL group, 20(39.2%) students changed their alternative conceptions for the scientifically accepted conception while 1(2.0%) student developed alternative conceptions as a result of the intervention. For the FCL group on the other hand, 15(30.6%) students changed their alternative conceptions for the scientifically accepted conception while as many as 7(14.3%) students developed alternative conceptions as a result of the intervention.

As shown in Table 18, for Question 5, the percentage of students with alternative conceptions decreased from 90.2% to 68.6% for the HACL group and also decreased from 98.0% to 75.5% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 7.692$ for HACL group and $\chi^2 = 9.090$ for the FCL group). However, as shown in Table 18, for the HACL group, 12(23.5%) students changed their alternative conceptions for the scientifically accepted conception while 1(2.0%) student developed alternative conceptions as a result of the intervention. For the FCL group on the other hand, 37(75.5%) students changed their alternative conceptions for the scientifically accepted conception with no student developing alternative conceptions as a result of the intervention.

As shown in Table 18, for Question 6, the percentage of students with alternative conceptions decreased from 86.3% to 18.4% for the HACL group but increased from 85.7% to 89.8% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 33.029$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = 1.125$). However, as shown in Table 18, for the HACL group, 35(68.6%) students changed their alternative conceptions for the scientifically accepted conception with no student developing alternative conceptions as a result of the intervention. For the FCL group on the other hand, 39(79.6%) students changed their alternative conceptions for the scientifically accepted conception while 5(10.2%) students developed alternative conceptions as a result of the intervention.

As shown in Table 18, for Question 7, the percentage of students with alternative conceptions decreased from 92.2% to 20.4% for the HACL group but increased from 87.8% to 91.8% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 35.027$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = 1.125$). However, as shown in Table 18, for the HACL group, 37(72.5%) students changed their alternative conceptions for the scientifically accepted conception with no student developing alternative conceptions as a result of the intervention. For the FCL group on the other hand, 40(81.6%) students changed their alternative conceptions for the scientifically accepted conception while 5(10.2%) students developed alternative conceptions as a result of the intervention.

As shown in Table 18, for Question 8, the percentage of students with alternative conceptions decreased from 74.5% to 11.8% for the HACL group but decreased from 77.6% to 28.6% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 30.031$ for HACL group and $\chi^2 = 17.633$ for the FCL group). However, as shown in Table 18, for the HACL group, 32(62.7%) students changed their alternative conceptions for the scientifically accepted conception with no student developing alternative conceptions as a result of the intervention. For the FCL group on the other hand, 11(22.4%) students changed their alternative conceptions for the scientifically accepted conception while 3(6.1%) students developed alternative conceptions as a result of the intervention.

As shown in Table 18, for Question 9, the percentage of students with alternative conceptions decreased from 88.2% to 21.6% for the HACL group and also decreased from 79.6% to 46.9% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 32.029$ for HACL group and $\chi^2 = 8.036$ for the FCL group). However, as shown in Table 18, for the HACL group, 36(70.6%) students changed their alternative conceptions for the scientifically accepted conception with no student developing alternative conceptions as a result of the intervention. For the FCL group on the other hand, 17(34.7%) students changed their alternative conceptions for the scientifically accepted conception while 6(12.2%) students developed alternative conceptions as a result of the intervention.

The specific conceptions the students in the HACL and FCL groups have for pretest and posttest have been discussed question by question as follows:

Question 1

Question 1 sought to find out whether students hold the scientific conception that 'when dry cells are connected in series, the effective voltage equals the algebraic sum of the voltages of the dry cells but when dry cells are connected in parallel, the equivalent voltage equals the voltage of one of the dry cells.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question one are presented in Table 19 and Table 20 respectively.

As shown in Table 19, one major alternative conception held by students in the pretest was that the more the number of dry cells connected in a circuit, the more the brightness. This was held by 31.3% and 20.4% of students in the HACL group and the FCL group respectively. This alternative conception decreased to 0%

and 4.1% for the HACL and FCL groups respectively in the posttest as shown in Table 20.

Table 19

Students' Alternative Conceptions on Question 1 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1.The more the number of dry cells the more the brightness.	16	31.4	10	20.4
2.Dry cells connected in series produce the brightest light followed by a single dry cell and finally by dry cells connected in parallel.	4	7.9	8	16.3
3.Brightness of bulb is the same irrespective of the number of dry cells connected.	6	11.8	3	6.1
4. Dry cells connected in parallel produce brighter light than those connected in series.	3	5.8	2	4.1
Total	**29**	**56.9**	**23**	**46.9**

Another major alternative conception held by students as shown in Table 19 was that dry cells connected in series produce the brightest light followed by a single dry cell and finally by dry cells connected in parallel. This alternative conception was initially held by 7.9% and 16.3% of students in the HACL and FCL groups respectively in the pretest. This alternative conception was slightly reduced to 5.9% and 6.1% for the HACL and FCL groups respectively in the posttest as shown in Table 20.

Table 20

Students' Alternative Conceptions on Question 1 for Posttest

Students' Alternative conception	HACL N	HACL %	FCL N	FCL %
1.The more the number of dry cells the more the brightness.	0	0.0	2	4.1
2. Dry cells connected in series produce the brightest light followed by a single dry cell and finally by dry cells connected in parallel.	3	5.9	3	6.1
3. Bulbs 'B' and 'C' have the same voltage which is twice the voltage of bulb 'A'.	1	1.9	1	2.0
Total	**4**	**7.8**	**6**	**12.2**

As shown in Table 19, another alternative conception held by students was that the brightness of the bulb is the same irrespective of the number of dry cells connected. This was held by 11.8% and 6.1% students in the HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest as shown in Table 20.

Another alternative conception held by students as shown in Table 19 was that dry cells connected in parallel produce brighter light than those connected in series. This was held by 5.8% and 4.1% students in the HACL and FCL groups respectively in the pretest. This conception was also given up by all the students in the two groups in the posttest as shown in Table 20.

Another alternative conception which showed up only in the posttest was that bulbs 'B' and 'C' have the same voltage which is twice the voltage of bulb 'A'. This was held by 1.9% and 2.0% students in the HACL and FCL groups respectively as shown in Table 20.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: This is because, as voltage increases, the current also increases and the more the dry cells, the more the flow of current through the bulbs and the brighter the bulbs.

SS: Bulb 'B' on circuit 2 will be brighter than bulb 'A' in circuit 1 whilst bulb 'C' will be the least because of the pressure exerted in parallel connection.

This implies that after the interventions, 92% of the students in the HACL group have the correct conception while 8% of the students have alternative conceptions and 88% of the students in the FCL group have the correct conception while 12% of the students have alternative conceptions to the scientifically correct concept that when dry cells are connected in series, the effective voltage equals the algebraic sum of the voltages of the dry cells but when dry cells are connected in parallel, the equivalent voltage equals the voltage of one of the dry cells.

Question 2

Question 2 sought to find out whether students hold the scientific conception that 'if resistor R_1 is decreased, the effective resistance in the circuit reduces which increases the brightness of the bulb simply because current is inversely proportional to resistance.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question two are presented in Table 21 and Table 22 respectively.

Table 21

Students' Alternative Conceptions on Question 2 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1.Reduction in resistance does not affect brightness of the bulb	10	19.6	8	16.3
2. Resistance is directly proportional to current and so reduction in resistance decreases brightness.	8	15.7	7	14.3
3.Voltage is directly proportional to resistance and so a decrease in resistance decrease voltage thereby decreasing the brightness.	5	9.8	5	10.2
4. The amount of voltage in the circuit reduces	2	3.9	0	0.0
Total	**25**	**49.0**	**20**	**40.8**

As shown in Table 21, one major alternative conception held by students in the pretest was that the reduction in resistance does not affect brightness of the bulb. This was held by 19.6% and 16.3% of students in the HACL group and the FCL group respectively. This alternative conception decreased to 5.9% and 2.0% for the HACL and FCL groups respectively in the posttest as shown in Table 22.

Table 22:

Students' Alternative Conceptions on Question 2 for Posttest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. Reduction in resistance does not affect brightness of the bulb	3	5.9	1	2.0
2. Resistance is directly proportional to current and so reduction in resistance decreases brightness.	1	2.0	0	0.0
3. Voltage is directly proportional to resistance and so a decrease in resistance decreases voltage thereby decreasing the brightness.	7	13.7	4	8.2
Total	**11**	**21.6**	**5**	**10.2**

Another major alternative conception held by students as shown in Table 21 was that resistance is directly proportional to current and so reduction in resistance decreases brightness. This alternative conception was held by 15.7% and 14.3% of students in the HACL and FCL groups respectively in the pretest. This alternative conception was reduced to 5.9% and 2.0% for the HACL and FCL groups respectively in the posttest as shown in Table 22.

As shown in Table 21, another alternative conception held by students was that voltage is directly proportional to resistance and so a decrease in resistance decreases voltage thereby decreasing the brightness. This was held by 9.8% and 10.1% students in the HACL and FCL groups respectively in the pretest. This conception alternative conception was reduced to 2.0% for the HACL and given up by students in the FCL groups in the posttest as shown in Table 22.

Another alternative conception held by students as shown in Table 21 was that the amount of voltage in the circuit reduces. This was held by 3.9% students in the HACL group and held by no student in the FCL groups in the pretest but was given up by that student in the HACL group in the posttest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: R_1 and R_2 are connected in series which implies that the total resistance $R_T = R_1 + R_2$ so if R_1 decreased, R_T will also decrease. However, voltage is also directly proportional to resistance and vice versa which means that with decrease in resistance, voltage will also decrease thereby decreasing the brightness of the bulb.

SS: The brightness of the bulb will be the same because when R_1 decreases, R_2 will support the bulb to bright at its normal level.

SS: The brightness of the bulb will increase because resistance R is directly proportional to current and so the brightness of the bulb will decrease.

This implies that after the interventions, 78% of the students in the HACL group have the correct conception while 22% of the students have alternative conceptions and 90% of the students in the FCL group have the correct conception while 10% of the students have alternative conceptions to the scientifically correct decreases voltage thereby decreasing the brightness. This was held by 9.8% and 10.1% students in the HACL and FCL groups respectively in the pretest. This conception alternative conception was reduced to 2.0% for the HACL and given up by students in the FCL groups in the posttest as shown in Table 22.

Another alternative conception held by students as shown in Table 21 was that the amount of voltage in the circuit reduces. This was held by 3.9% students in the HACL group and held by no student in the FCL groups in the pretest but was given up by that student in the HACL group in the posttest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: R_1 and R_2 are connected in series which implies that the total resistance $R_T = R_1 + R_2$ so if R_1 decreased, R_T will also decrease. However, voltage is also directly proportional to resistance and vice versa which means that with decrease in resistance, voltage will also decrease thereby decreasing the brightness of the bulb.

SS: The brightness of the bulb will be the same because when R_1 decreases, R_2 will support the bulb to bright at its normal level.

SS: The brightness of the bulb will increase because resistance R is directly proportional to current and so the brightness of the bulb will decrease.

This implies that after the interventions, 78% of the students in the HACL group have the correct conception while 22% of the students have alternative conceptions and 90% of the students in the FCL group have the correct conception while 10% of the students have alternative conceptions to the scientifically correct concept that if resistor R_1 is decreased, the effective resistance in the circuit reduces which increases the brightness of the bulb since current is inversely proportional to resistance.

Question 3

Question 3 sought to find out whether students hold the scientific conception that 'since bulbs 'B' and 'C' are connected in series, the source voltage will be shared between them which will make their brightness reduce while bulbs 'A', 'D' and 'E' connected in parallel will be equal since the voltage across them is the same.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question three are presented in Table 23 and Table 24 respectively.

Table 23

Students' Alternative Conceptions on Question 3 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. Bulbs 'A' and 'B' have the same brightness since they take direct current from the positive terminal followed by bulb 'C' and finally bulbs 'D' and 'E' because they are connected in parallel.	13	25.5	10	20.4
2. Bulb 'A' takes all the voltage whereas bulbs in series receive more voltage and so give off brighter light than bulbs in parallel.	10	19.6	9	18.4
3. Brightness of bulbs 'A', 'B' and 'C' are equal since the same current flow through them.	7	13.7	12	24.5

Table 23, continued

4.Voltage in circuit 3 is shared between bulbs 'D' and 'E' and have the lowest brightness.	8	15.7	5	10.2
5. Current will be shared between bulbs 'B' and 'C' in circuit 2 and also between bulbs 'D' and 'E' in circuit 3.	5	9.8	6	12.2
6. No explanation.	4	7.8	2	4.1
Total	**47**	**92.2**	**44**	**89.8**

As shown in Table 23, one major alternative conception held by students in the pretest was that bulbs 'A' and 'B' have the same brightness since they take direct current from the positive terminal, followed by bulb 'C' and finally bulbs 'D' and 'E' because they are connected in parallel. This was held by 25.5% and 20.4% of students in the HACL group and the FCL group respectively. This alternative conception decreased to 7.8% and 14.3% for the HACL and FCL groups respectively in the posttest as shown in Table 24.

Another major alternative conception held by students as shown in Table 23 was that bulb 'A' takes all the voltage whereas bulbs in series receive more voltage and so give off brighter light than bulbs in parallel. This alternative conception was held by 19.6% and 18.4% of students in the HACL and FCL groups respectively in the pretest. This alternative conception was reduced to 13.7% for the HACL group in the posttest but the same 18.4% of the students in the FCL group as in the pretest maintained their alternative conceptions without changing them in the posttest as shown in Table 24.

Table 24

Students' Alternative Conceptions on Question 3 for Posttest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. Bulb 'A' takes all the voltage whereas bulbs in series receive more voltage and so give off brighter light than bulbs in parallel.	7	13.7	9	18.4
2. Bulbs 'A' and 'B' have the same brightness since they take direct current from the positive terminal followed by bulb 'C' and finally bulbs 'D' and 'E' because they are connected in parallel.	4	7.8	7	14.3
3. Current will be shared between bulbs 'B' and 'C' in circuit 2 and also between bulbs 'D' and 'E' in circuit 3.	6	11.8	5	10.2
4. Brightness of bulbs 'A', 'B' and 'C' are equal since the same current flow through them.	3	5.9	8	16.3
Total	**20**	**39.2**	**29**	**59.2**

Another major alternative conception held by students as shown in Table 23 was that the brightness of bulbs 'A', 'B' and 'C' are equal since the same current flow through them. This alternative conception was held by 13.7% and 24.5% of students in the HACL and FCL groups respectively in the pretest. This alternative conception decreased to 5.9% and 16.3% for the HACL and FCL groups respectively in the posttest as shown in Table 24.

Another major alternative conception held by students as shown in Table 23 was that the voltage in circuit 3 is shared between bulbs 'D' and 'E' and have the lowest brightness. This alternative conception was held by 15.7% and 10.2% of students in the HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest.

As shown in Table 23, another alternative conception held by students was that current will be shared between bulbs 'B' and 'C' in circuit 2 and also between bulbs 'D' and 'E' in circuit 3. This was held by 9.8% and 12.2% students in the HACL and FCL groups respectively in the pretest. This alternative conception increased to 11.8% for the HACL group but decreased to 10.2% for the FCL group in the posttest as shown in Table 24.

As shown in Table 23, 7.8% and 4.1% of the students in the HACL and FCL groups respectively did not give any explanations for their reasoning in the pretest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: Bulbs 'A', 'B' and 'C' have the same brightness because circuits 1 and 2 are arranged in series and that the same voltage runs through the bulbs but in circuit 3 the bulbs are arranged in parallel and so the voltage is shared equally between the bulbs.

SS: The brightness of bulbs connected in series is the same that is A = B = C and bulbs connected in parallel are also equal in brightness but less brighter than those connected in series.

This implies that after the interventions, 61% of the students in the HACL group have the correct conception while 39% of the students have alternative conceptions and only 41% of the students in the FCL group have the correct conception while 59% of the students have alternative conceptions to the scientifically correct concept that since bulbs 'B' and 'C' are connected in series, the source voltage will be shared between them which will make their brightness reduce while bulbs 'A', 'D' and 'E' connected in parallel will be equal since the voltage across them is the same.

Question 4

Question 4 sought to find out whether students hold the scientific conception that 'the source current through bulb 'A' will be shared equally between bulbs 'B' and 'C' which will make their brightness reduce and then the current will recombine before flowing through bulb 'D.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question four are presented in Table 25 and Table 26 respectively.

As shown in Table 25, one major alternative conception held by students in the pretest was that current from the terminal will get first to bulb 'A' which will make it have the most of the current followed by bulbs 'B' and 'C' since they are connected in parallel and bulb 'D' gets the least current. This was held by 31.4% and 24.5% of the students in the HACL group and the FCL group respectively. This alternative conception decreased to 9.8% and 6.1% for the HACL and FCL groups respectively in the posttest as shown in Table 26.

Table 25

Students' Alternative Conceptions on Question 4 for Pretest

Students' Alternative conception	HACL N	HACL %	FCL N	FCL %
1. Current from the terminal will get first to bulb 'A' which will make it have the most of the current followed by bulbs 'B' and 'C' since they are connected in parallel and bulb 'D' gets the least current.	16	31.4	12	24.5
2.Bulbs 'A' and 'D' are closer to the terminals of the dry cells and receive much current but bulb 'B' and 'C' will receive equal current.	5	9.8	10	20.4
3.Bulbs in series receive greater percentage of voltage from the dry cell but bulbs in parallel share the voltage from the dry cell.	7	13.7	2	4.1
4.The circuit is closed and so no current will flow.	3	5.9	3	6.1
5.The bulbs will have the same brightness since the source voltage will be shared equally among the bulbs.	4	7.8	1	2.0
Total	**35**	**68.6**	**28**	**57.1**

Another major alternative conception held by students as shown in Table 25 was that bulbs 'A' and 'D' are closer to the terminals of the dry cells and receive much current but bulb 'B' and 'C' will receive equal current. This alternative conception was held by 9.8% and 20.4% of the students in the HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest.

Another major alternative conception held by students as shown in Table 25 was that bulbs in series receive greater percentage of voltage from the dry cell but bulbs in parallel share the voltage from the dry cell. This alternative conception was held by 13.7% and 4.1% of students in the HACL and FCL groups respectively in the pretest. This alternative conception decreased to 5.9% for the HACL group but increased to 10.2% for the FCL group in the posttest as shown in Table 26.

Table 26

Students' Alternative Conceptions on Question 4 for Posttest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1.Current from the terminal will get first to bulb 'A' which will make it have the most of the current followed by bulbs 'B' and 'C' since they are connected in parallel and bulb 'D' gets the least current.	5	9.8	3	6.1
2. The bulbs will have the same brightness since the same voltage will pass through all the bulbs.	8	15.7	12	24.5
3. Bulbs in series receive greater percentage of voltage from the dry cell but bulbs in parallel share the voltage from the dry cell.	3	5.9	5	10.2
Total	**16**	**31.4**	**20**	**40.8**

As shown in Table 25, another alternative conception held by students was that the circuit is closed and so no current will flow. This was held by 5.9% and 6.1% students in the HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest.

Another alternative conception held by students as shown in Table 25 was that the bulbs will have the same brightness since the source voltage will be shared equally among the bulbs. This alternative conception was held by 7.8% and 2.0% of students in the HACL and FCL groups respectively in the pretest. This conception was also given up by all the students in the two groups in the posttest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: This is because, bulb 'A' receives direct current from the dry cell and bulbs 'B' and 'C' are connected in parallel so they share the same charges but because it passes through bulb 'A' first, the current flow will reduce before it gets to bulbs 'B' and 'C' and reduce again after passing through bulbs 'B' and 'C'. Therefore, bulb 'D' will have the least brightness since the current flow will be low at that point.

SS: Bulbs 'A' and 'D' will be equal since they are closer to the terminals of the dry cells. This is because the emf from the terminals after passing through bulbs 'A' and 'D' will divide into two equal parts between bulbs 'B' and 'C' thereby reducing the brightness.

This implies that after the interventions, 69% of the students in the HACL group have the correct conception while 31% of the students have alternative conceptions and 59% of the students in the FCL group have the correct conception while 41% of the students have alternative conceptions to the scientifically correct concept that the source current through bulb 'A' will be shared equally between bulbs 'B' and 'C' which will make their brightness reduce and then the current will recombine before flowing through bulb 'D.

Question 5

Question 5 sought to find out whether students hold the scientific conception that 'the source voltage is shared equally across bulbs 'A', 'B' and 'D to allow the same current to flow but bulb 'C' will not light because the key is open.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question five are presented in Table 27 and Table 28 respectively.

Table 27

Students' Alternative Conceptions on Question 5 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1.No current will flow in the circuit.	35	68.6	34	69.4
2.Bulb 'A' will get the greatest current followed by bulbs 'B' and 'C' and finally	4	7.8	5	10.2
3.All the bulbs will have the same brightness since the current through them is the same. bulb 'D'.	3	5.9	4	8.2
4. No explanation.	4	7.8	5	10.2
Total	**46**	**90.2**	**48**	**98.0**

As shown in Table 27, one major alternative conception held by students in the pretest was that no current will flow in the circuit. This was held by 68.6% and 69.4% of students in the HACL group and the FCL group respectively. This alternative conception decreased slightly to 58.8% and 63.3% for the HACL and FCL groups respectively in the posttest as shown in Table 28.

Another alternative conception held by students as shown in Table 27 was that bulb ‘A’ will get the greatest current followed by bulbs ‘B’ and ‘C’ and finally. This alternative conception was held by 7.8% and 10.2% of students in the HACL and FCL groups respectively in the pretest. This alternative conception increased slightly to 9.8% and 12.2% for the HACL and FCL groups respectively in the posttest as shown in Table 28.

Table 28

Students' Alternative Conceptions on Question 5 for Posttest

	HACL		FCL	
Students’ Alternative conception	N	%	N	%
1.No current will flow in the circuit.	30	58.8	31	63.3
2. Bulb ‘A’ will get the greatest current followed by bulbs ‘B’ and ‘C’ and finally bulb ‘D’.	5	9.8	6	12.2
Total	**35**	**68.8**	**37**	**75.5**

As shown in Table 27, another alternative conception held by students was that all the bulbs will have the same brightness since the current through them is the same. This alternative conception was held by 5.9% and 8.2% of students in the

HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest.

As shown in Table 27, 7.8% and 10.2% of the students in the HACL and FCL groups respectively did not give any explanations for their reasoning in the pretest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: This is because current flows in a circular manner and so when the circuit is open the current will also stop flowing.

SS: When the circuit is open current flows from the dry cell to bulb 'A' but at the point of parallel connection between bulbs 'B' and 'C', the current is halved but the circuit is open at bulb 'C' hence gives no light but half current moves through bulbs 'B' and 'D'.

This implies that after the interventions, only 31% of the students in the HACL group have the correct conception while 69% of the students have alternative conceptions and 24% of the students in the FCL group have the correct conception while 76% of the students have alternative conceptions to the scientifically correct concept that the source voltage is shared equally across bulbs 'A', 'B' and 'D to allow the same current to flow but bulb 'C' will not light because the key is open.

Question 6

Question 6 sought to find out whether students hold the scientific conception that 'potential difference or voltage is always measured across circuit components and not across wires.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question six are presented in Table 29 and Table 30 respectively.

Table 29

Students' Alternative Conceptions on Question 6 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. The potential difference is the same in the circuit and does not change.	29	56.9	18	36.7
2.Points 1 and 2 will have the highest potential difference followed by points 2 and 3 and finally points 3 and 4 because potential difference is consumed at each point.	2	3.9	10	20.4
3.The voltage is shared equally among the three given points.	3	5.9	3	6.1
4.When the potential difference moves across any bulb its value is halved.	3	5.9	2	4.1
5. No explanation.	7	13.7	9	18.4
Total	**44**	**86.3**	**42**	**85.7**

As shown in Table 29, one major alternative conception held by students in the pretest was that the potential difference is the same in the circuit and does not change. This was held by 56.9% and 36.7% of students in the HACL group and the

FCL group respectively. This alternative conception decreased to 9.8% for the HACL group but increased to 71.4% for the FCL group in the posttest as shown in Table 30.

Table 30

Students' Alternative Conceptions on Question 6 for Posttest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. The potential difference is the same in the circuit and does not change.	5	9.8	35	71.4
2. Points 1 and 2 will have the highest potential difference followed by points 2 and 3 and finally points 3 and 4 because potential difference is consumed at each point.	4	7.8	9	8.4
Total	**9**	**17.6**	**44**	**89.8**

Another alternative conception held by students as shown in Table 29 was that points 1 and 2 will have the highest potential difference followed by points 2 and 3 and finally points 3 and 4 because potential difference is consumed at each point. This alternative conception was held by 3.9% and 20.4% of students in the HACL and FCL groups respectively in the pretest. This alternative conception increased slightly to 7.8% and 18.4% for the HACL and FCL groups respectively in the posttest as shown in Table 30.

As shown in Table 29, another alternative conception held by students was that the voltage is shared equally among the three given points. This alternative conception was held by 5.9% and 6.1% of students in the HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest.

Another alternative conception held by students as shown in Table 29 was that when the potential difference moves across any bulb its value is halved. This alternative conception was held by 5.9% and 4.1% of students in the HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest.

As shown in Table 29, 13.7% and 18.4% of the students in the HACL and FCL groups respectively did not give any explanations for their reasoning in the pretest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: This is because when the potential difference moves across any bulb it is halved and there is one bulb between point 2 and 3, therefore it changes from 6V to 3V.

SS: This is because since the voltage is 6V, the potential difference will be the same throughout the wire hence between any two points the potential difference is 6V.

This implies that after the interventions, 82% of the students in the HACL group have the correct conception while 18% of the students have alternative conceptions and only 10% of the students in the FCL group have the correct conception while 90% of the students have alternative conceptions to the scientifically correct concept that potential difference or voltage is always measured across circuit components and not across wires.

Question 7

Question 7 sought to find out whether students hold the scientific conception that 'the source voltage will be shared equally between the two bulbs.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question seven are presented in Table 31 and Table 32 respectively.

Table 31

Students' Alternative Conceptions on Question 7 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. Potential difference remains the same throughout the circuit.	22	43.1	17	34.7
2. Most of the voltage is consumed by the first bulb and the remaining by the second bulb.	9	17.6	11	22.4
3.Voltage will be shared equally to all the three given points.	6	11.8	6	12.2
4. No explanation.	10	19.6	9	18.4
Total	**47**	**92.2**	**43**	**87.8**

As shown in Table 31, one major alternative conception held by students in the pretest was that the potential difference remains the same throughout the circuit. This was held by 43.1% and 34.7% of students in the HACL group and the FCL group respectively. This alternative conception decreased to 9.8% for the HACL group but increased to 44.9% for the FCL group in the posttest as shown in Table 32.

Table 32:

Students' Alternative Conceptions on Question 7 for Posttest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. Potential difference remains the same throughout the circuit.	5	9.8	22	44.9
2.Voltage will be shared equally to all the three given points.	2	3.9	15	30.6
3.Most of the voltage is consumed by the first bulb and the remaining by the second bulb.	3	5.9	8	6.3
Total	**10**	**19.6**	**43**	**87.8**

Another major alternative conception held by students as shown in Table 31 was that most of the voltage is consumed by the first bulb and the remaining by the second bulb. This alternative conception was held by 17.6% and 22.4% of students in the HACL and FCL groups respectively in the pretest. This alternative conception decreased to 5.9% and 16.3% for the HACL and FCL groups respectively in the posttest as shown in Table 32.

As shown in Table 31, another alternative conception held by students was that the voltage will be shared equally to all the three given points. This alternative conception was held by 11.8% and 12.2% of students in the HACL and FCL groups respectively in the pretest. This alternative conception decreased to 3.9% for the HACL group but increased to 30.6 for the FCL group in the posttest as shown in Table 32.

As shown in Table 31, 19.6% and 18.4% of the students in the HACL and FCL groups respectively did not give any explanations for their reasoning in the pretest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: From point 1 to 2, the voltage remains the same as that of the dry cell but between points 2 and 3 the voltage decreases because of the presence of the bulb. Between points 3 and 4 the voltage reduces again due to the bulb between point 3 and 4.

SS: This is because the voltage needed to light a bulb is 3V hence between points 1 and 2, 6V is used, between points 2 and 3, 3V is used, and hence 3V is left to be used between points 3 and 4.

SS: Between points 1 and 2, 3V is used and between points 2 and 3, the voltage reduces by 3V because of absorption by the bulb. The voltage finally reduces to 0V between points 3 and 4.

This implies that after the interventions, 80% of the students in the HACL group have the correct conception while 20% of the students have alternative conceptions and only 12% of the students in the FCL group have the correct conception while 88% of the students have alternative conceptions to the scientifically correct concept that the source voltage will be shared equally between the two bulbs.

Question 8

Question 8 sought to find out whether students hold the scientific conception that 'the current in the circuit remains the same since charges are not consumed by circuit components.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question eight are presented in Table 33 and Table 34 respectively.

Table 33

Students' Alternative Conceptions on Question 8 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. The bulb uses part of the current in lighting and so makes 1 > 2.	36	70.6	31	63.3
2. The resistance of point 1 is decreased while that of point 2 is increased.	0	0.0	1	2.0
3. No explanation.	2	3.9	6	12.2
Total	**38**	**74.5**	**38**	**77.6**

As shown in Table 33, one major alternative conception held by students in the pretest was that the bulb uses part of the current in lighting and so makes 1 > 2. This was held by 70.6% and 63.3% of students in the HACL group and the FCL group respectively. This alternative conception decreased to 11.8% and 2.9% for the HACL and FCL groups respectively in the posttest as shown in Table 34.

Another alternative conception held by only 2.0% of students in the FCL group as shown in Table 33 was that the resistance of point 1 is decreased while that of point 2 is increased but this conception was given up by the student in the posttest.

Table 34

Students' Alternative Conceptions on Question 8 for Posttest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. The bulb uses part of the current in lighting and so makes 1 > 2.	6	11.8	14	2.9

As shown in Table 33, 3.9% and 12.2% of the students in the HACL and FCL groups respectively did not give any explanations for their reasoning in the pretest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: When a circuit is closed current passes through point 1 before reaching point 2. In between points 1 and 2 is a bulb which provides some resistance and also consumes some amount of current to light thereby reducing the amount of current reaching point 2.

SS: Point 1 is closer to the cell more than point 2 and so will have greater current.

This implies that after the interventions, 88% of the students in the HACL group have the correct conception while 12% of the students have alternative conceptions and 97% of the students in the FCL group have the correct conception while 3% of the students have alternative conceptions to the scientifically correct concept that the current in the circuit remains the same since charges are not consumed by circuit components.

Question 9

Question 9 sought to find out whether students hold the scientific conception that 'the source voltage will be the same for all the branches but at every branch the voltage will be shared among the bulbs equally.' The number and percentage of students with alternative conceptions and the type of alternative conceptions they have on pretest and posttest with respect to question nine are presented in Table 35 and Table 36 respectively.

Table 35

Students' Alternative Conceptions on Question 9 for Pretest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1. Bulb 'A' will receive most of the current first before any other bulb and so will be the brightest and the current will then be shared among bulbs 'B', 'C' and 'D'.	21	41.2	11	22.4
2. The voltage will be the same for all the bulbs since they are connected in parallel.	10	19.6	12	24.5
3. Current from the dry cell will be shared equally between bulbs 'A' and 'B' since they are connected in parallel but decrease	8	15.7	6	12.2

Table 35, continued

before it gets to bulbs 'C and 'D'.				
4. Bulbs 'B', 'C' and 'D' have the maximum brightness since they are connected in series.	4	7.8	5	10.2
5. No explanation.	2	3.9	5	10.2
Total	**45**	**88.2**	**39**	**79.6**

As shown in Table 35, one major alternative conception held by students in the pretest was that the bulb 'A' will receive most of the current first before any other bulb and so will be the brightest and the current will then be shared among bulbs 'B', 'C' and 'D'. This was held by 41.2% and 22.4% of students in the HACL group and the FCL group respectively. This alternative conception decreased to 7.8% and 12.2% for the HACL and FCL groups respectively in the posttest as shown in Table 36.

Another major alternative conception held by students as shown in Table 35 was that the voltage will be the same for all the bulbs since they are connected in parallel. This alternative conception was held by 19.6% and 24.5% of students in the HACL and FCL groups respectively in the pretest. This alternative conception decreased to 5.9% and 14.3% for the HACL and FCL groups respectively in the posttest as shown in Table 36.

Table 36

Students' Alternative Conceptions on Question 9 for Posttest

	HACL		FCL	
Students' Alternative conception	N	%	N	%
1.Current from the dry cell will be shared equally between bulbs 'A' and 'B' since they are connected in parallel but decrease before it gets to bulbs 'C and 'D'.	4	7.8	10	20.4
2.The voltage will be the same for all the bulbs since they are connected in parallel.	3	5.9	7	14.3
3. Bulb 'A' will receive most of the current first before any other bulb and so will be the brightest and the current will then be shared among bulbs 'B', 'C' and 'D'.	4	7.8	6	12.2
Total	**11**	**21.6**	**23**	**46.9**

As shown in Table 35, another alternative conception held by students was that the current from the dry cell will be shared equally between bulbs 'A' and 'B' since they are connected in parallel but decrease before it gets to bulbs 'C and 'D'. This alternative conception was held by 15.7% and 12.2% of the students in the HACL and FCL groups respectively in the pretest. This alternative conception decreased to 7.8% for the HACL group but increased to 20.4% for the FCL group in the posttest as shown in Table 36.

Another alternative conception held by students as shown in Table 35 was that Bulbs 'B', 'C' and 'D' have the maximum brightness since they are connected in series. This alternative conception was held by 7.8% and 10.2% of the students in the HACL and FCL groups respectively in the pretest. This conception was however given up by all the students in the two groups in the posttest.

As shown in Table 35, 3.9% and 10.2% of the students in the HACL and FCL groups respectively did not give any explanations for their reasoning in the pretest.

Examples of some of the responses from students' (SS) transcripts are as follows:

SS: Because the bulbs are identical the current that flow through them is the same, therefore the brightness of the bulbs will be the same.

SS: This is because electrons flow from the positive terminal to bulb 'A' which will have the highest brightness and then move to bulbs 'B', 'C' and 'D' which will have less and equal brightness because they are in series.

SS: Bulb 'A' is parallel to the rest of the bulbs and so will get full current whilst the others divide the current among themselves.

This implies that after the interventions, 78% of the students in the HACL group have the correct conception while 22% of the students have alternative conceptions and 53% of the students in the FCL group have the correct conception while 47% of the students have alternative conceptions to the scientifically correct concept that the source voltage will be the same for all the branches but at every branch the voltage will be shared among the bulbs equally.

In summary, the HACL grouping method was superior in changing students' alternative conceptions in electric circuits than the FCL grouping method. This is because the degree of changes in students' alternative conceptions was significant in all the nine questions when the HACL grouping method was used but the degree of changes in students' alternative conceptions was significant only in six of the nine questions when the FCL grouping method was used.

Furthermore, questions in ECCT were scored quantitatively and the pretest and posttest mean scores for students in the HACL and FCL groups were compared using the t-test for independent samples. This further confirmed the results of the qualitative analysis performed earlier. Table 37 shows the results of independent samples t-test for pretest mean scores of HACL and FCL groups for ECCT.

Table 37

Results of Independent Samples t-test for Pretest Mean Scores of HACL and FCL Groups for ECCT

Variable	Group	N	Mean	SD	t	df	p
	HACL	51	3.96	2.81			
Pretest					1.263	98	.210
	FCL	49	4.68	2.93			

Not significant, since $p > 0.05$

As shown in Table 37, there was no statistically significant difference between the mean scores of students in the HACL and FCL groups with respect to ECCT before instruction ($t(98) = 1.263$, $p = .210$). The results indicate that on the average, students in both groups had similar levels of preconceptions and that they had started the treatments with nearly the same level of learning.

To investigate possible significant difference in performance between the HACL and FCL groups in the posttest of ECCT, the groups' mean scores were compared using the t-test for independent samples. Table 38 shows that results of independent samples t-test for posttest mean scores of HACL and FCL groups for ECCT.

Table 38

Results of Independent Samples t-test for posttest Mean Scores of HACL and FCL groups for ECCT

Variable	Group	N	Mean	SD	t	df	p
Posttest	HACL	52	13.12	3.42	6.205	98	.000*
	FCL	49	9.04	3.14			

Significant, since $p < 0.05$

As shown in Table 38, there is a statistically significant difference between the two groups' posttest mean scores with respect to ECCT ($t(99) = 6.205, p < .001$). The HACL group ($M = 13.12$, $SD = 3.42$) outperformed their counterparts in the FCL group ($M = 9.04$, $SD = 3.14$).

Based on these findings, null hypothesis two of no statistically significant difference in the degree of changes in conception about concepts in electric circuits between the HACL group and the FCL group was rejected. The findings from this study is consistent with the findings in literature that students at every level hold alternative conceptions in electric circuits and it takes a prudent method to remediate such alternative conceptions (Afra, Osta & Zoubeir, 2009, Cepni & Keles, 2005; Engelhardt & Beichner, 2004; İpek & Çalık , 2008; Lee & Law, 2001; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; McDermott &

Shaffer 1992). Among these alternative conceptions, the most prevailing ones were the 'attenuation' and 'sharing' models of current, battery as a constant source of current, voltage-current confusion, failure to realize that the resistance of an element is its own property and that a change at one point in the circuit affects the entire circuit, more elements in the circuit, more resistance, and failure to identify series and parallel networks. The identified difficulties were not solely conceptual; they were also related to students' types of reasoning. In fact, every student demonstrated, at least once, a difficulty in reasoning holistically about a circuit; instead they often exhibited local and, to a lesser extent, sequential types of reasoning. These types of reasoning were noticeably manifested when the students were asked to evaluate the behaviour of circuits when dynamic changes were made to a circuit.

Many of the persisting alternative conceptions can be attributed to students' sequential and local reasoning about a circuit (Borges & Gilbert, 1999). The results showed that local reasoning was harder to abort than sequential reasoning, and consequently, the conceptions related to local reasoning such as the sharing model of current and battery as a constant source of current were harder to overcome compared to those related to sequential reasoning such as the attenuation model of current.

Though both the HACL and FCL grouping methods showed various decreases in their abilities to change students' alternative conceptions in electric circuits which confirms the claim by Zacharia (2007) that inquiry-based teaching approaches have been found to be effective for changing students' alternative conceptions, it was not a surprise when students in the HACL group were superior in changing their alternative conception in this study than students in the FCL group. This success could be explained through three ways. Firstly, group members in the HACL group were more engaged in active learning behaviours which promoted each other's success than in the FCL group because according to Kagan (1990), when the group did not structure for equal participation, the group discussion session could involve participation exclusively by the HD students. Secondly, the EI student in the HACL group engaged in frequent and open discussion than their counterparts in the FCL group which subsequently increased their ability to develop more complex level of understanding and reasoning which helped them to develop scientifically correct conceptions (Abdullah & Shariff, 2008). Thirdly, the HD students through hypothetical-deductive reasoning test their preconceptions against scientific concepts and find out which one match experimental results. This brings about restructuring mental models leading to promotion of conceptual change (Fah, 2009). The HD students in the HACL group appear to be more successful in changing their conceptions than HD students in the FCL group. This explanations supports the evidence in the previous results where both the HD and EI students in the HACL group outperformed HD and EI students in the FCL group in conceptual understanding and scientific reasoning.

Comparison of Posttest Mean Scores in Scientific Reasoning and Conceptual Understanding of Electric circuits between HD students in HACL and FCL groups

Hypothesis three sought to test whether there was no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between HD senior high school 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. Since there were no statistically significant difference in the pretest mean scores of the HD students in both groups for scientific reasoning and conceptual understanding of concepts in electric circuit at the pre-experimental results, MANOVA was used to investigate possible differences in performance between HD students in the two groups in post-SR and post-CU. Table 39 presents the descriptive statistics for each dependent variable for HD students by groups.

As shown in Table 39, the HD students in the two groups had relatively different mean scores in post-SR: 8.39 and 7.59 for HACL group and FCL group respectively with the means score of HACL group being higher. The mean scores of the HD students in the two groups were also relatively different in post-CU: 23.76 and 20.32 for HACL group and FCL group respectively with the means score of HACL group being higher.

Table 39

Means and Standard Deviations for Post-SR and Post-CU for HD students by Groups

Dependent Variable		HACL (N=21)	FCL (N=22)
Post-SR	Mean	8.39	7.59
	SD	1.07	.85
Post-CU	Mean	23.76	20.32
	SD	1.97	1.77

Note: Total score for Post-CU = 30, and total score for Post-SR = 12

Table 40 shows the summary of MANOVA results for the HD students on scientific reasoning and conceptual understanding of electric circuits for posttest. The Pillai's Trace was used to evaluate the MANOVA differences.

Table 40

Summary of MANOVA Effect for HD students in Post-SR and Post-CU of Electric Circuits

Dependent Variables	Multivariate F	Pillai's Trace	df	p	Partial Eta Squared
Post-SR Post-CU	20.693	.509	2, 40	.001*	.51

*Significant, since $p < .05$

As shown in Table 40, there was a statistically significant difference in mean scores between HD students in the HACL and FCL groups on the combined dependent variables: $F(2, 40) = 20.693$, $p < .001$, *Pillai's Trace* = .509, *partial eta squared* = .51. Thus, the type of instructional method had significantly influence students' scientific reasoning and conceptual understanding of electric circuits. This means the instructional method accounted for 51% of the variance of the dependent variables.

Furthermore, the results of univariate ANOVA of between-subjects effects of HD students in HACL and FCL on scientific reasoning and conceptual understanding of electric circuits for posttest is presented in Table 41.

Table 41

Summary of the follow-up analysis of variance (ANOVA) results of HD students on Post-SR and Post-CU

Dependent variable	Univariate F	df	p	Partial Eta Squared
Post-SR	7.18	1, 41	.011*	.15
Post-CU	38.31	1, 41	.001*	.48

*Significant, since $p < .05$

When the results for the dependent variables were considered separately for the HD students in HACL and FCL groups as shown in Table 41, there was a statistically significant difference in mean scores, using the Bonferroni adjusted alpha level of .025, for both post-SR: $F(1, 41) = 7.18$, $p = .011$, partial eta squared = .15 and post-CU: $F(1, 41) = 38.31$, $p < .001$, partial eta squared = .48. This means the instructional method a main effect which accounted for 15% of the variance in post-SR and also accounted for 48% of the variance in post-CU. An inspection of the mean scores as presented in Table 40 and the results of univariate ANOVA as shown in Table 41 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.

Based on these findings, null hypothesis three of no statistically significant difference in performance between HD students in the HACL group and those in the FCL group in (a) scientific reasoning was rejected and (b) conceptual understanding of electric circuits was also rejected. These results support the findings of Abdullah and Shariff (2008) that HD students in the heterogeneous-ability group outperformed their counterparts in the friendship-ability group in conceptual understanding of electric circuits 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. By doing this, the HD students clarify and reorganise the concepts to make it understandable to themselves and their EI counterparts. Such elaborative thought according to Saleh and De Jong (2005) 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.

Comparison of Posttest Mean Scores in Scientific Reasoning and Conceptual Understanding between EI students in HACL and FCL groups

Hypothesis four sought to test whether there was no statistically significant difference in (a) scientific reasoning and (b) conceptual understanding of electric circuits between EI senior high school 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. Since there were no statistically significant differences in the pretest mean scores of the EI students in both groups for scientific reasoning and conceptual understanding of electric circuits at the pre-experimental results, MANOVA was used to investigate possible differences in performance between EI students in the two groups in post-SR and post-CU. Table 42 presents the descriptive statistics for each dependent variable for EI students by groups.

As shown in Table 42, the EI students in the two groups had relatively different mean scores in post-SR: 6.48 and 5.38 for HACL group and FCL group respectively with the means score of HACL group being higher. The mean scores of the EI students in the two groups were also relatively different in post-CU: 18.67 and 14.76 for HACL group and FCL group respectively with the means score of HACL group being higher.

Table 42

Means and Standard Deviations for Post-SR and Post-CU for EI students by Groups

Dependent Variable		HACL (N=33)	FCL (N=29)
Post-SR	Mean	6.48	5.38
	SD	.94	1.12
Post-CU	Mean	18.67	14.76
	SD	2.18	2.17

Note: Total score for post-SR = 12, and total score for post-CU = 30

Table 43 shows the summary of MANOVA results for the EI students on scientific reasoning and conceptual understanding of electric circuits for posttest. The Pillai's Trace was used to evaluate the MANOVA differences.

As shown in Table 43, there was a statistically significant difference in mean scores between EI students in the HACL and FCL groups on the combined dependent variables: $F(2, 59) = 43.366$, $p < .001$, *Pillai's Trace* = .595. Thus, the type of instructional method had a significant influence students' scientific reasoning and conceptual understanding of electric circuits. This means the instructional methods accounted for 60% of the variance of the dependent variables (*partial eta squared* = .60).

Table 43

Summary of MANOVA Effect for EI students in Post-SR and Post-CU of Electric Circuits

Dependent Variables	Multivariate F	Pillai's Trace	df	p	Partial Eta Squared
Post-SR					
	43.366	.595	2, 59	.001*	.60
Post-CU					

*Significant, since $p < .05$

Furthermore, the results of univariate ANOVA of between-subjects effects of EI students in HACL and FCL on scientific reasoning and conceptual understanding of electric circuits for posttest is presented in Table 44.

Table 44

Summary of the follow-up analysis of variance (ANOVA) results of EI students on Post-SR and Post-CU

Dependent variable	Univariate F	df	p	Partial Eta Squared
Post-SR	17.95	1, 60	.001*	.23
Post-CU	50.04	1, 60	.001*	.46

*Significant, since $p < .05$

When the results for the dependent variables were considered separately for the EI students in HACL and FCL groups as shown in Table 44, there was a statistically significant difference in mean scores, using the Bonferroni adjusted alpha level of .025, for both post-SR: $F(1, 60) = 17.95, p < .001$ and post-CU: $F(1, 60) = 50.04, p < .001$. This means the instructional method a main effect which accounted for 23% of the variance in post-SR (*partial eta squared* = .23) and also accounted for 46% of the variance in post-CU (*partial eta squared* = .46). An inspection of the mean scores as presented in Table 29 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.

Based on these findings, null hypothesis four of no statistically significant difference in performance between EI students in the HACL group and those in the FCL group in (a) scientific reasoning was rejected and (b) conceptual understanding of electric circuits was also rejected. These results support the findings of Abdullah and Shariff (2008) that EI students in the HACL group outperformed their counterparts in the FCL group in conceptual understanding of electric circuits 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 (Remigio et al., 2014). 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 (Johnson et al., 1998). 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 was done to examine whether there are interaction effects between the instructional methods and students' scientific reasoning ability levels (EI reasoning ability and HD reasoning ability) in performance for (a) scientific reasoning (b) conceptual understanding of electric circuits. Table 45 presents the overall means, standard deviations, adjusted means and standard errors for the different dependent variables by the interaction between instructional methods and scientific reasoning levels (EI reasoning ability and HD reasoning ability).

Table 45

Descriptive statistics for the different Dependent Variables by the Interaction between Instructional Methods and Scientific Reasoning Levels

Instructional Methods	Moderator Variables		Dependent Variable SR	CU
HACL	HD (N=21)	Mean	8.38	23.75
		SD	1.07	1.92
		Adj, Mean	8.292	24.126
		Std. Error	.303	.612

Table 45, continued

	EI (N=33)	Mean	6.48	18.67
		SD	.94	2.18
		Adj, Mean	6.557	18.383
		Std. Error	.227	.459
FCL	HD (N=22)	Mean	7.59	20.23
		SD	.85	1.77
		Adj, Mean	7.450	20.736
		Std. Error	.291	.589
	EI (N=29)	Mean	5.38	14.76
		SD	1.12	2.17
		Adj, Mean	5.468	14.432
		Std. Error	.230	.466

Note: Total score for SR = 12, and total score for CU = 30. Covariates that appeared in the model were evaluated as pre-SR = 5.33 and pre-CU = 12.76

To examine if the effects of instructional methods (HACL and FCL grouping methods) on scientific reasoning and conceptual understanding of electric circuits depend on scientific reasoning levels in the HACL group and FCL groups, while controlling for pre-SR and pre-CU, a two-way multivariate analysis of covariance (MANCOVA) was conducted. Preliminary checks were conducted to ensure that there was no violation of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes and reliable measurement of the covariates [see APPENDIX R SPSS Output for assumption testing of MANCOVA].

Table 46 presents the results of a two-way MANCOVA, showing the overall differences in the interaction between instructional methods and scientific reasoning levels in their effect on the two dependent variables while controlling for pre-SR and pre-CU. Pillai's Trace was used to evaluate the multivariate (MANCOVA) differences. As shown in Table 46, the MANCOVA results showed that there was no statistically significant interaction effect between instructional method and students' scientific reasoning levels as they relate to SR and CU of electric circuits ($F(3,101) = .464, p = .63$). The covariates pre-SR ($F(2, 98) = 1.966$, $p = .15$) and pre-CU ($F(2, 98) = 1{,}152, p = .32$) also had no statistically significant effects. Furthermore, results of ANCOVA as shown in Table 46 indicated that there were no statistically significant interaction effects across the two groups in SR ($F(1, 99) = .473, p = .49$) and CU ($F(1, 99) = .376, p = .54$).

Table 46

Summary of MANCOVA results by the Interaction Effects and follow-up Analysis of Covariance (ANCOVA) across the Two Groups

MANCOVA Effect Dependent Variables and Covariates	Multivariate F Pillai's Trace	Univariate F df=1, 99	Partial Eta Squared
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

These results were confirmed by plotting the interaction between the instructional method and students' scientific reasoning levels on SR and CU as shown in Figure 5 and Figure 6, respectively. As shown in Figure 4 and Figure 5, there were no interaction effects of the instructional method and students' scientific reasoning levels on SR and CU across the two groups.

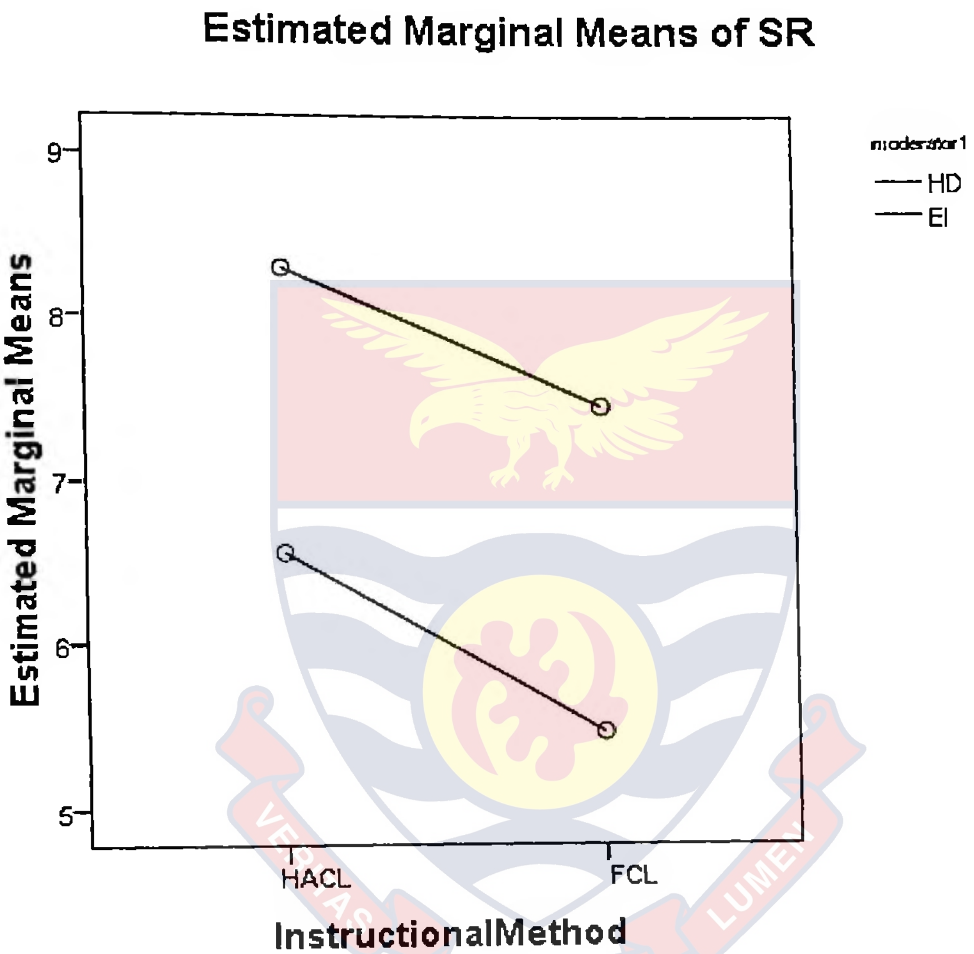

Figure 4: Interaction effect between the instructional method and students' scientific reasoning levels on SR.

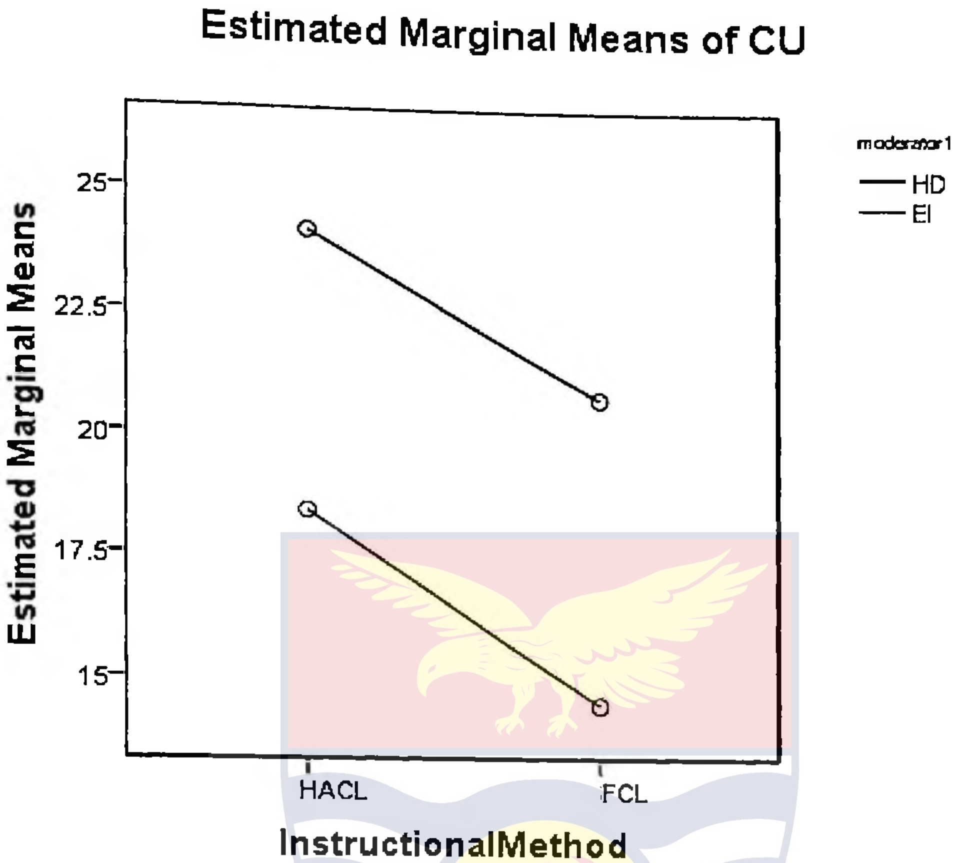

Figure 5: Interaction effect between the instructional method and students' scientific reasoning levels on CU.

These results suggests 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. These results indicated that both the HD and EI students benefited equally in terms of scientific reasoning and conceptual understanding of electric circuits after learning through HACL or FCL grouping methods. This means that there is the high possibility that when students of the same characteristics are instructed through these methods elsewhere, it will yield similar results. This finding supports the study by Abdullah and Shariff (2008) 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.

Comparison of the Degree of Changes in Conception of Electric Circuits between HD students in the HACL and FCL Groups

Hypothesis five sought to investigate whether there was no statistically significant difference in the degree of changes in conception in electric circuits between senior high school HD 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. To test this hypothesis, analysis was done to find out the degree of change of students' alternative conception in electric circuits from pretest to the posttest for the responses provided by the HD students on Electric Circuits Conception Test (ECCT). The number and percentage of HD students with alternative conceptions and the type of alternative conception they have in the concepts of electric circuits for both the pretest and posttest were also determined.

To determine the degree of changes in HD students' alternative conceptions from the pretest to the posttest for each question for the two groups, the McNemar chi square test for significance of changes was used. The degree of changes in HD students' alternative conception for HACL and FCL groups from the pretest to the posttest for each question was calculated using the McNemar formula and presented in Table 47 [see APPENDIX P for extended version of Table 47].

Table 47

Degree of Changes in HD Students' Alternative Conceptions by Question

	HACL group [N = 21]			FCL group [N = 23]		
Question	Pretest	Posttest	χ^2	Pretest	Posttest	χ^2
1	9(42.9)	1(4.8)	4.900*	8(34.8)	1(4.3)	5.143*
2	8(38.1)	1(4.8)	4.000*	8(34.8)	0(.0)	6.125*
3	20(95.2)	4(19.0)	14.063*	19(82.6)	7(30.4)	8.643*
4	13(61.9)	2(9.5)	9.091*	11(47.8)	4(17.4)	2.769
5	18(85.7)	9(42.9)	7.111*	23(100.0)	15(65.2)	6.125*
6	18(85.7)	2(9.5)	14.063*	19(82.6)	19(82.6)	.000
7	20(95.2)	0(.0)	18.050*	20(87.0)	20(87.0)	.000
8	13(61.9)	2(9.5)	9.091*	19(82.6)	3(13.0)	14.063*
9	16(76.2)	1(4.8)	13.067*	17(73.9)	6(26.1)	5.263*

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

As shown in Table 47, for Question 1, the percentage of HD students with alternative conceptions decreased from 42.9% to 4.8% for the HACL group and also decreased from 34.9% to 4.3% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant (χ^2 = 4.900 for HACL group and χ^2 = 5.143 for the FCL group). However, as shown in Table 47, for the HACL group, 9 (42.9%) of the HD students changed their alternative conceptions for the scientifically accepted conception while only 1(4.8%) of the HD students developed an alternative conception as a result of the intervention. For the FCL group on the other hand, 7(30.4%) of the HD students changed their alternative conceptions for the scientifically accepted conception while no HD student developed alternative conception as a result of the intervention.

As shown in Table 47, for Question 2, the percentage of students with alternative conceptions decreased from 38.1% to 4.8% for the HACL group and also decreased from 34.8% to 0% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 4.000$ for HACL group and $\chi^2 = 6.125$ for the FCL group). However, as shown in Table 47, for the HACL group, 8(38.1%) of the HD students changed their alternative conceptions for the scientifically accepted conception while 1(4.8%) of them developed alternative conceptions as a result of the intervention. For the FCL group on the other hand, 8(34.8%) of the HD students changed their alternative conceptions for the scientifically accepted conception while no HD student developed alternative conception as a result of the intervention.

As shown in Table 47, for Question 3, the percentage of students with alternative conceptions decreased from 95.2% to 19.0% for the HACL group and also decreased from 82.6% to 30.4% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 14.063$ for HACL group and $\chi^2 = 8.643$ for the FCL group). However, as shown in Table 47, for the HACL group, 16(76.2%) of the HD students changed their alternative conceptions for the scientifically accepted conception while no HD student developed alternative conception as a result of the intervention. For the FCL group on the other hand, 13(56.5%) of the HD students changed their alternative conceptions for the scientifically accepted conception while only 1(4.3%) of them developed alternative conceptions as a result of the intervention.

As shown in Table 47, for Question 4, the percentage of students with alternative conceptions decreased from 61.9% to 9.5% for the HACL group and also decreased slightly from 47.8% to 17.4% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 9.091$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = 2.769$). However, as shown in Table 47, for the HACL group, 11(52.4%) of the HD students changed their alternative conceptions for the scientifically accepted conception while no HD student developed alternative conception as a result of the intervention. For the FCL group on the other hand, 10(43.5%) of the HD students changed their alternative conceptions for the scientifically accepted conception while 3(13.0%) of them developed alternative conceptions as a result of the intervention.

As shown in Table 47, for Question 5, the percentage of students with alternative conceptions decreased from 85.7% to 42.9% for the HACL group and also decreased from 100% to 65.2% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 7.111$ for HACL group and $\chi^2 = 6.125$ for the FCL group). However, as shown in Table 47, for the HACL group, 9(42.9%) of the HD students changed their alternative conceptions for the scientifically accepted conception while no HD student developed alternative conception as a result of the intervention. For the FCL group on the other hand, 8(34.8%) of the HD students changed their alternative conceptions for the scientifically accepted conception with no HD student developing alternative conception as a result of the intervention.

As shown in Table 47, for Question 6, the percentage of students with alternative conceptions decreased from 85.7% to 9.5% for the HACL group but remained at 82.6% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 14.063$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = .000$). However, as shown in Table 47, for the HACL group, 16(76.2%) of the HD students changed their alternative conceptions for the scientifically accepted conception with no HD student developing alternative conception as a result of the intervention. For the FCL group on the other hand, 3(13.0%) of the HD students changed their alternative conceptions for the scientifically accepted conception while 3(13.0%) of them developed alternative conceptions as a result of the intervention.

As shown in Table 47, for Question 7, the percentage of students with alternative conceptions decreased from 95.2% to 0% for the HACL group but remained at 87.0% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 18.050$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = .000$). However, as shown in Table 47, for the HACL group, 20(95.2%) of the HD students changed their alternative conceptions for the scientifically accepted conception with no HD student developing alternative conception as a result of the intervention. For the FCL group on the other hand, 2(8.7%) of the HD students changed their alternative conceptions for the scientifically accepted conception while 2(8.7%) of them developed alternative conceptions as a result of the intervention.

As shown in Table 47, for Question 8, the percentage of students with alternative conceptions decreased from 61.9% to 9.5% for the HACL group and decreased from 82.6% to 13.0% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 9.091$ for HACL group and $\chi^2 = 14.063$ for the FCL group). However, as shown in Table 47, for the HACL group, 11(52.4%) of the HD students changed their alternative conceptions for the scientifically accepted conception with no HD student developing alternative conception as a result of the intervention. For the FCL group on the other hand, 16(69.6%) of the HD students changed their alternative conceptions for the scientifically accepted conception while no HD student developed alternative conception as a result of the intervention.

As shown in Table 47, for Question 9, the percentage of students with alternative conceptions decreased from 76.2% to 4.8% for the HACL group and decreased from 73.9% to 26.1% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 13.067$ for HACL group and $\chi^2 = 5.263$ for the FCL group). However, as shown in Table 47, for the HACL group, 15(71.4%) of the HD students changed their alternative conceptions for the scientifically accepted conception with no HD student developing alternative conception as a result of the intervention. For the FCL group on the other hand, 15(65.2%) of the HD students changed their alternative conceptions for the scientifically accepted conception while 4(17.4%) of them developed alternative conceptions as a result of the intervention.

In summary, the HACL grouping method was superior in changing HD students' alternative conceptions in electric circuits than the FCL grouping method. This is because the degree of changes in students' alternative conceptions was significant in all the nine questions when the HACL grouping method was used but the degree of changes in students' alternative conceptions was significant only in six of the nine questions when the FCL grouping method was used. Based on these findings, null hypothesis five of no statistically significant difference in the degree of changes in conceptions about concepts in electric circuits between HD students in the HACL group and those in the FCL group was rejected. This finding supports the claim that students learn more and test their conceptions better when engaged in explaining concepts constantly to their peers (Fah, 2009; Lou et al., 1996; Saleh & De Jong, 2005). HD students in the HACL group were constantly engaged in explaining concepts, providing immediate feedbacks and providing guidance to their EI counterparts in the groups. This increased their understanding and exposed deficiencies in their taught which might have led them to changing their alternative conceptions than HD students in the FCL group. HD students in the FCL group on the other hand, were not as engaged in providing explanations and guidance to their EI peers as exhibited by HD students in the HACL group since there were homogeneous-ability groups in the FCL group.

Comparison of the Degree of Changes in Conception of Electric Circuits between EI students in the HACL and FCL groups

Hypothesis six sought to investigate whether there was no statistically significant difference in the degree of changes in conception in electric circuits between senior high school EI 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. To test this hypothesis, analysis was done to find out the degree of change of students' alternative conception in electric circuits from pretest to the posttest for the responses provided by the EI students on Electric Circuits Conception Test (ECCT). The number and percentage of EI students with alternative conceptions and the type of alternative conception they have in the concepts of electric circuits for both the pretest and posttest were also determined.

To determine the degree of changes in EI students' alternative conceptions from the pretest to the posttest for each question for the two groups, the McNemar chi square test for significance of changes was used. The degree of changes in EI students' alternative conception for HACL and FCL groups from the pretest to the posttest for each question was calculated using the McNemar formula and presented in Table 48 [see Appendix Q for extended version of Table 48].

As shown in Table 48, for Question 1, the percentage of students with alternative conceptions decreased from 66.7% to 10.0% for the HACL group and also decreased from 57.7% to 19.2% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found to be statistically significant ($\chi^2 = 15.059$ for HACL group and $\chi^2 = 5.786$ for the FCL group). However, as shown in Table 48, for the HACL group, 17(56.7%) of the EI students changed their alternative conceptions for the scientifically accepted conception while no EI student developed an alternative conception as a result of the intervention. For the FCL group on the other hand, 12(46.2%) of the EI students changed their alternative conceptions for the scientifically accepted conception while 2(7.7%) of them developed alternative conceptions as a result of the intervention.

Table 48

Degree of Changes in EI Students' Alternative Conceptions by Question

	HACL group [N = 30]			FCL group [N = 26]		
Question	Pretest	Posttest	χ^2	Pretest	Posttest	χ^2
1	20(66.7)	3(10.0)	15.059*	15(57.7)	5(19.2)	5.786*
2	17(56.7)	10(33.3)	2.118	12(46.2)	5(19.2)	3.273
3	27(90.0)	16(39.2)	7.692*	25(96.2)	20(55.1)	2.286
4	22(73.3)	14(46.7)	4.900*	17(65.4)	16(61.5)	.000
5	28(93.3)	26(86.7)	.250	25(96.2)	22(84.6)	1.333
6	26(86.7)	7(23.3)	17.053*	23(88.5)	25(96.2)	.500
7	27(90.0)	10(33.3)	15.059*	23(88.5)	25(96.2)	.250
8	25(83.3)	4(13.3)	19.048*	19(73.1)	11(42.3)	3.500
9	29(96.7)	10(33.3)	17.053*	22(84.6)	17(65.4)	1.778

Figures in parenthesis are percentages *Significant at $\chi^2 \geq 3.84$

As shown in Table 48, for Question 2, the percentage of students with alternative conceptions decreased from 56.7% to 33.3% for the HACL group and also decreased from 46.2% to 19.2% for the FCL group. The decrease in alternative conceptions in the HACL and FCL groups were found not to be statistically significant ($\chi^2 = 2.118$ for HACL group and $\chi^2 = 3.273$ for the FCL group). However, as shown in Table 48, for the HACL group, 12(40.0%) of the EI students changed their alternative conceptions for the scientifically accepted conception while 5(16.7%) of them developed alternative conceptions as a result of the intervention. For the FCL group on the other hand, 9(34.6%) of the EI students changed their alternative conceptions for the scientifically accepted conception while 2(7.7%) of them developed alternative conceptions as a result of the intervention.

As shown in Table 48, for Question 3, the percentage of students with alternative conceptions decreased from 90.0% to 39.2% for the HACL group and also decreased slightly from 96.2% to 55.1% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 7.692$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = 2.286$). However, as shown in Table 48, for the HACL group, 12(40.0%) of the EI students changed their alternative conceptions for the scientifically accepted conception while 1(3.3%) EI student developed alternative conception as a result of the intervention. For the FCL group on the other hand, 6(23.1%) of the EI students changed their alternative conceptions for the scientifically accepted conception while 1(3.8%) of them developed alternative conception as a result of the intervention.

As shown in Table 48, for Question 4, the percentage of students with alternative conceptions decreased from 73.3% to 46.7% for the HACL group and also decreased slightly from 65.4% to 61.5% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 4.900$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = .000$). However, as shown in Table 48, for the HACL group, 9(30.0%) of the EI students changed their alternative conceptions for the scientifically accepted conception while 1(3.3%) EI student developed alternative conception as a result of the intervention. For the FCL group on the other hand, 5(19.2%) of the EI students changed their alternative conceptions for the scientifically accepted conception while 4(15.4%) of them developed alternative conceptions as a result of the intervention.

As shown in Table 48, for Question 5, the percentage of students with alternative conceptions decreased from 93.3% to 86.7% for the HACL group and also decreased from 96.2% to 84.6% for the SFCL group. The decrease in alternative conceptions in the HACL and FCL groups were found not to be statistically significant (χ^2 = .250 for HACL group and χ^2 = 1.333 for the FCL group). However, as shown in Table 48, for the HACL group, 3(10.0%) s of the EI students changed their alternative conceptions for the scientifically accepted conception while 1(3.3%) student developed alternative conception as a result of the intervention. For the FCL group on the other hand, 3(11.5%) EI students changed their alternative conceptions for the scientifically accepted conception with no EI student developing alternative conceptions as a result of the intervention.

As shown in Table 48, for Question 6, the percentage of students with alternative conceptions decreased from 86.7% to 23.3% for the HACL group but increased from 88.5% to 96.2% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant (χ^2 = 17.053) while the change in the FCL group was found not to be statistically significant (χ^2 = .500). However, as shown in Table 48, for the HACL group, 19(63.3%) of the EI students changed their alternative conceptions for the scientifically accepted conception with no EI student developing alternative conception as a result of the intervention. For the FCL group on the other hand, no EI student changed his alternative conception for the scientifically accepted conception while 2(7.7%) EI students developed alternative conceptions as a result of the intervention.

As shown in Table 48, for Question 7, the percentage of students with alternative conceptions decreased from 90.0% to 33.3% for the HACL group but increased from 88.5% to 96.2% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 =$ 15.059) while the change in the FCL group was found not to be statistically significant ($\chi^2 = .250$). However, as shown in Table 48, for the HACL group, 17(56.7%) EI students changed their alternative conceptions for the scientifically accepted conception with no EI student developing alternative conception as a result of the intervention. For the FCL group on the other hand, 1(3.8%) EI student changed his alternative conception for the scientifically accepted conception while 3(11.5%) EI students developed alternative conceptions as a result of the intervention.

As shown in Table 48, for Question 8, the percentage of students with alternative conceptions decreased from 83.3% to 13.3% for the HACL group and decreased from 73.1% to 42.3% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 =$ 19.048) while the change in the FCL group was found not to be statistically significant ($\chi^2 = 3.500$). However, as shown in Table 48, for the HACL group, 21(70.0%) EI students changed their alternative conceptions for the scientifically accepted conception with no EI student developing alternative conception as a result of the intervention. For the FCL group on the other hand, 11(42.3%) EI students changed their alternative conceptions for the scientifically accepted conception while 3(11.5%) EI students developed alternative conceptions as a result of the intervention.

As shown in Table 48, for Question 9, the percentage of students with alternative conceptions decreased from 96.7% to 33.3% for the HACL group and decreased from 84.6% to 65.4% for the FCL group. The decrease in alternative conceptions in the HACL group was found to be statistically significant ($\chi^2 = 17.053$) while the change in the FCL group was found not to be statistically significant ($\chi^2 = 1.778$). However, as shown in Table 48, for the HACL group, 19(63.3%) EI students changed their alternative conceptions for the scientifically accepted conception with no EI student developing alternative conception as a result of the intervention. For the FCL group on the other hand, 7(26.9%) EI students changed their alternative conceptions for the scientifically accepted conception while 2(7.7%) EI students developed alternative conceptions as a result of the intervention.

In summary, the HACL grouping method was superior in changing EI students' alternative conceptions in electric circuits than the FCL grouping method. This is because the degree of changes in students' alternative conceptions was significant in seven of the nine questions when the HACL grouping method was used but the degree of changes in students' alternative conceptions was significant only in one of the nine questions when the FCL grouping method was used. Based on these findings, null hypothesis six of no statistically significant difference in the degree of changes in conception about concepts in electric circuits between EI students in the HACL group and those in the FCL group was rejected. The success of the HACL method in changing EI students' alternative conceptions is consistent with cognitive developmental perspectives of both Piaget and Vygotsky that cooperative learning with more able peers result in cognitive development and intellectual growth (Johnson, Johnson & Smith, 1998). Piagetian perspectives suggest that when individual work together, socio-cognitive conflict occurs and creates cognitive disequilibrium that stimulates perspective – talking ability and reasoning. It is also consistent with the social cohesion theory that claims that HD students in a group help EI students to move toward HD reasoning (Slavin, 1996). Both HD and EI students in the HACL groups engaged in active learning which promoted the success of each group member. This gave the EI students in the HACL groups the opportunity to compare and contrast their conceptions and reasoning with their HD counterparts which was not always the case in the FCL groups.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Overview of the study

This study was conducted to investigate the extent to which the combination of inquiry-based real hands-on and computer simulation methods would affect Senior High School students' scientific reasoning, conceptual understanding, and conceptual change 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) in the Cape Coast Metropolis. The study tested the six null hypotheses at .05 level of significance.

In all, 110 Form 2 students offering physics, chemistry, biology and mathematics as electives in two intact classes were randomly sampled using computer generated random numbers from two senior high schools in the Cape Coast Metropolis to participate in the study. A quasi-experimental pretest-posttest-delayed posttest method which employed a 2 x 2 Factorial Design with 55 students in one intact class from one of the schools designated as the HACL group and another 55 students from another school designated as the FCL group was used in this study. The HACL group was instructed using the combination of inquiry-based real hands-on and computer simulations methods with heterogeneous-ability cooperative learning [HACL] grouping while the FCL group was instructed using the combination of inquiry-based real hands-on and computer simulations methods with friendship cooperative learning [FCL] grouping. Both groups took pretests on scientific reasoning and conceptual understanding before the interventions to ascertain their prior knowledge on the concepts in electric circuits. After the various instructions, students took posttests on scientific reasoning and conceptual understanding to determine students' academic achievements regarding the strategies used and a delayed posttest after one month to measure the extent to which the concepts of electric circuits learned have been sustained. The researcher taught all the 12 lessons (i.e., six lessons in each group) in collaboration with the class teachers.

The study used a combination of quantitative and qualitative research methods to collect data. The quantitative data comprised the pretest, posttest and delayed posttest scores on scientific reasoning and conceptual understanding of electric circuits. The qualitative data comprised of qualitative reasons students gave to the nine questions in ECCT. These were used to identify students' alternative conception in electric circuits for both pretest and posttest.

The main limitation of this study was that not all the students attended all lesson sessions which showed clearly in the reduction in the sample sizes for the groups during the posttest. This could have affected the outcome of this study.

Key findings

1. Comparison of posttest mean scores in scientific reasoning and conceptual understanding between HACL and FCL groups.

It was found that there was no statistically significant difference in mean scores between the HACL ($M = 6.19$, $SD = 2.23$) and FCL ($M = 6.13$, $SD = 1.77$) groups with respect to scientific reasoning: $F(1, 104) = .017$, $p = .90$ but 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: $F(1, 104) = 29.51$, $p < .001$.

2. Comparison of the degree of changes in conception of electric circuits between the HACL and FCL groups.

Many more students in the HACL group changed their alternative conceptions more effectively than students in the FCL group. This was because the degree of change in students' alternative conceptions was significant ($\chi^2 \geq 3.84$) in all the nine questions for the HACL group but the degree of change was significant in only six of the nine questions for the FCL group.

3. Comparison of posttest mean scores in scientific reasoning and conceptual understanding of electric circuits between HD students in HACL and FCL groups.

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 scientific reasoning: $F(1, 41) = 7.18$, $p = .011$ 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 conceptual understanding of electric circuits.

4. Comparison of posttest mean scores in scientific reasoning and conceptual understanding of electric circuits between EI students in HACL and FCL groups.

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 scientific reasoning: $F(1, 60) = 17.95$, $p < .001$ 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 conceptual understanding of electric circuits: $F(1, 60) = 50.04$, $p < .001$.

5. Comparison of the degree of changes in conception of electric circuits between HD students in the HACL and FCL groups.

The HACL grouping method was superior in changing HD students' alternative conceptions in electric circuits than the FCL grouping method. This is because the degree of changes in students' alternative conceptions was significant ($\chi^2 \geq 3.84$) in all the nine questions when the HACL grouping method was used while the degree of changes in students' alternative conceptions was significant in only six of the nine questions when the FCL grouping method was used.

6. Comparison of the degree of changes in conception of electric circuits between EI students in the HACL and FCL groups.

The HACL grouping method was superior in changing EI students' alternative conceptions in electric circuits than the FCL grouping method. This is because the degree of changes in students' alternative conceptions was significant ($\chi^2 \geq 3.84$) in seven of the nine questions when the HACL grouping method was used while the degree of changes in students' alternative conceptions was significant in only one of the nine questions when the FCL grouping method was used.

Conclusions

Based on the findings of this study a number of conclusions can be drawn. Related to the comparison of students' posttest mean scores in scientific reasoning and conceptual understanding between HACL and FCL groups, a number of conclusions can be drawn. Firstly, 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 and helping students retain the concepts of electric circuits than the use of the combination of inquiry-based real hands-on and computer simulation methods with FCL grouping. Secondly, the HACL method was found to be more effective for teaching most of the interrelated concepts in electric circuits as indicated in the instructional objectives than the FCL method. Thirdly, the HACL group outperformed their counterparts in the FCL group in conservational reasoning and proportional reasoning. Based on this, null hypothesis one was partly confirmed. These findings above 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 these 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.

The comparison of the degree of changes in students' conception of electric circuits between the HACL and FCL groups showed that the HACL method was superior in changing students' alternative conceptions in electric circuits more effectively than the FCL method. Based on this finding, null hypothesis two was rejected. This finding confirms the claim by Zacharia (2007) that inquiry-based teaching approaches have been found to be effective for changing students' alternative conceptions. However, it appears that no study in literature, if any, has shown how combination of inquiry-based real hands-on and computer simulation methods with HACL grouping can promote conceptual change as this study has brought to the fore. This seem to suggest that the combination of inquiry-based real hands-on and computer simulation methods with HACL grouping has a higher potential of helping students to change their alternative conceptions and should be employed when conceptual change is the focus of instruction.

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. Based on the above findings, null hypotheses three and four were rejected. These findings confirm the claim by Abdullah and Shariff (2008) that placing students in heterogeneous-ability cooperative learning groups promotes scientific reasoning and conceptual understanding. Though this was confirmed in this study, Abdullah and Shariff instructed the students using only computer simulations but this study used the combination of inquiry-based real hands-on and computer simulation methods for instruction. 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.

Related to the comparison of the degree of changes in conception of electric circuits between HD and EI students in the HACL and FCL groups, the HACL method was superior in changing both HD and EI students' alternative conceptions in electric circuits than the FCL method. Based on the above findings, null hypotheses five and six were rejected. These findings have filled the gap in literature which have failed to show how the HACL method can be used to change HD and EI students' alternative conceptions in electric circuits. This was shown in this study. The implication of this is that should there be the need to consider using a method to change HD and EI students' alternative conception, the HACL method should be used. This is because in such groupings both the HD and EI students have the opportunity the compare and construct their conceptions and reasoning which subsequently lead to conceptual change.

Recommendations

Recommendations for policy and practice

Based on the findings of this study, the following recommendations have been made for educational policy and practice in the teaching of electric circuits:

1. Physics teachers should use the combination of inquiry-based real hands-on and computer simulation method with heterogeneous-ability cooperative learning grouping in teaching concepts in electric circuits at the senior high school level in order to promote scientific reasoning and conceptual understanding.
2. 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.
3. Combination of inquiry-based real hands-on and computer simulations method with heterogeneous-ability cooperative learning grouping should be used in changing students' alternative conceptions of electric circuits in senior high schools.
4. Teachers should monitor the changes in alternative conceptions of both HD and EI students the course of their study.

Suggestions for Further Research

1. 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.
2. Further research should be conducted using the combination of inquiry-based real hands-on and computer simulation methods with heterogeneous-

ability cooperative learning grouping in other concepts in physics to ascertain whether it can be used across a number of concepts.

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APPENDICES

APPENDIX A

AVERAGE AGE OF STUDENTS IN THE HACL AND FCL GROUPS

FCL GROUP	AGE	HACL GROUP	AGE
A1	17	B1	16
A2	16	B2	16
A3	15	B3	17
A4	16	B4	17
A5	17	B5	15
A6	18	B6	16
A7	18	B7	16
A8	17	B8	16
A9	19	B9	18
A10	15	B10	16
A11	16	B11	16
A12	16	B12	17
A13	17	B13	16
A14	16	B14	17
A15	18	B15	17
A16	17	B16	17
A17	17	B17	16
A18	16	B18	16
A19	16	B19	16
A20	15	B20	18
A21	17	B21	15
A22	17	B22	15
A23	18	B23	17
A24	19	B24	17
A25	18	B25	16
A26	18	B26	16
A27	17	B27	16
A28	16	B28	16
A29	16	B29	17
A30	16	B30	17
A31	17	B31	15
A32	17	B32	18
A33	17	B33	18
A34	18	B34	16
A35	15	B35	16

FCL GROUP	AGE	HACL GROUP	AGE
A36	16	B36	16
A37	16	B37	17
A38	17	B38	16
A39	20	B39	16
A40	15	B40	17
A41	15	B41	16
A42	17	B42	16
A43	16	B43	16
A44	16	B44	16
A45	17	B45	16
A46	16	B46	16
A47	16	B47	17
A48	16	B48	16
A49	17	B49	17
A50	17	B50	17
A51	17	B51	17
A52	16	B52	16
A53	16	B53	16
A54	16	B54	16
A55	18	B55	15
Average	16.69	Average	16.35
Combined Average		16.5	

APPENDIX B

Distribution of Scores obtained in GALT in Pretest for the HACL and FCL Groups (Out of 12)

HACL group			FCL group		
Score	N	%	Score	N	%
1	1	1.8	1	2	3.6
2	3	5.5	2	2	3.6
3	8	14.5	3	7	12.7
4	11	20.0	4	7	12.7
5	7	12.7	5	11	20.0
6	4	7.3	6	3	5.5
7	16	29.1	7	15	27.3
8	3	5.5	8	7	12.7
9	2	3.6	9	1	1.8
Total	**55**	**100**		**55**	**100**

Grand mean for HACL group = 5.24 Grand mean for FCL group = 5.42

APPENDIX C

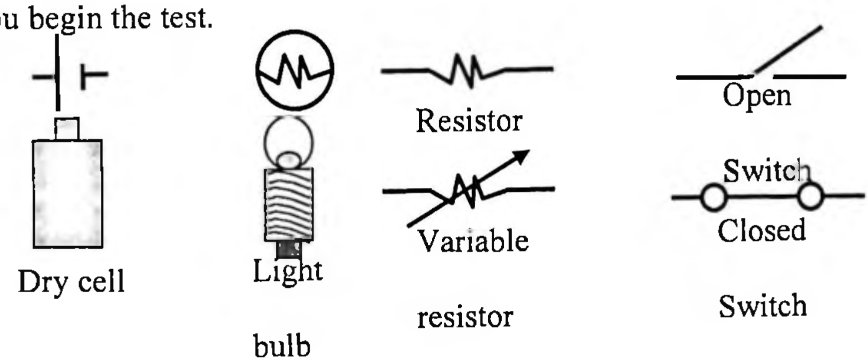
CURRENT ELECTRICITY CONCEPTS ACHIEVEMENT TEST (CECAT)

PLEASE READ THE FOLLOWING INSTRUCTIONS:

1. This test has nothing to do with your final grade.
2. Please carefully answer each question.
3. Each item has only one CORRECT response [Feel free to use the calculator].
4. For each item, use pencil to circle round the correct response in the answer booklet. Do all rough work on the blank sheets provided at the back of the answer booklet.
5. You have 1 hour to complete the test. If you finish early, kindly go over your work to check for errors before handing in both the answer and test booklets.

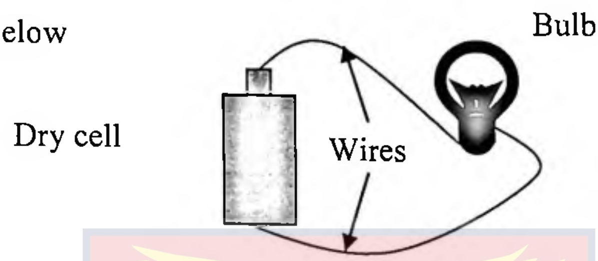
ADDITIONAL COMMENTS ABOUT THE TEST

All light bulbs, resistors and dry cells (battery) should be considered identical unless you are told otherwise. The battery is to be assumed as ideal (i. e. with negligible internal resistance). Also, assume the wires have negligible resistance. Below is a key to the symbols used in this test. Study them carefully before you begin the test.



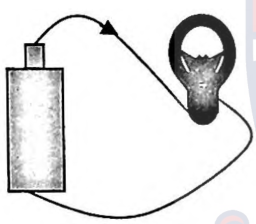
Please read the questions carefully before selecting your response. The questions have three to five options, lettered A to E. Circle the correct option for each question.

1. A dry cell is connected up to a bulb and the bulb glows as shown in the diagram below



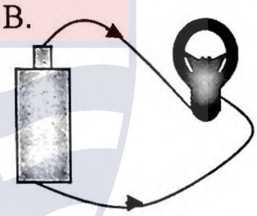
Which of the following best describes the path of the electric current in the wires?

A.



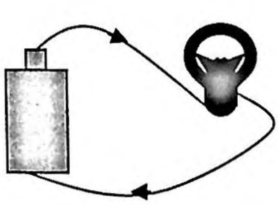
There will be no electric current in the wire attached to the base of the cell

B.



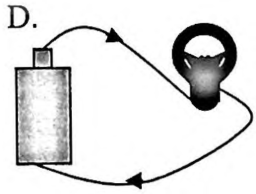
The electric current will be in a direction towards the bulb in both wires.

C.



The direction of the electric current will be as shown and the current will be less in the 'return' wire as shown.

D.



The direction of the electric current will be as shown and the current will be same in both wires.

2. Do charges in a wire get used up in a light bulb when converted to light?

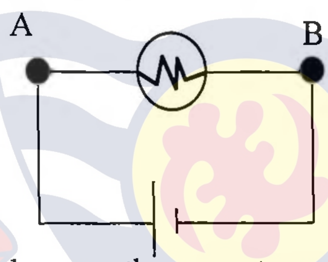
   A. Yes, charges moving through the filament produce 'friction' which heats up the filament and produces light?

   B. Yes, charges are emitted to the bulb.

   C. No, charges are conserved or not emitted. They are only converted to another form of energy such as heat and light.

   D. No, charges are conserved. Charges moving through the filament produce 'friction' which heats up the filament to produce light.

3. Compare the current at point 'A' to the current at point 'B' as shown in the diagram. Which point has the larger current?



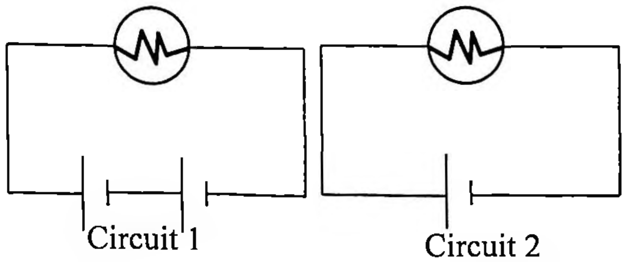
   A. Point 'A' because the current passes through it before point 'B.'

   B. Point 'A' because the bulb will consume some of the current.

   C. Both points have the same current.

   D. Point 'B' because current increase as it moves along.

4. Comparing the brightness of the bulb in circuit 1 to the bulb in circuit 2, which of them will be brighter? [Remember that the bulbs and dry cells are identical]

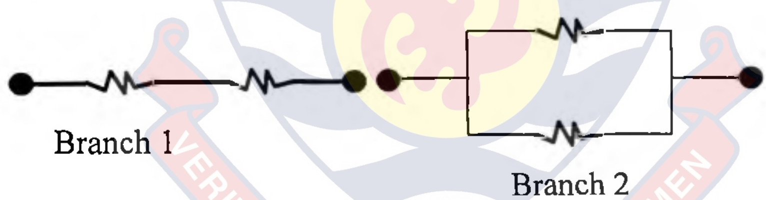


A. Bulb in circuit 1

B. Bulb in circuit 2

C. Both bulbs will have the same brightness

5. If the resistors have the same resistance, which of the two branches of the circuits shown below represents the branch with the least effective resistance?

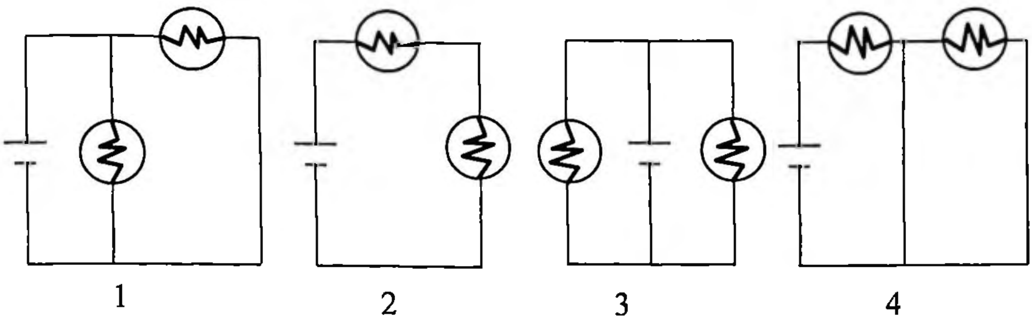


A. Branch 1

B. Branch 2

C. Both Branches are the same.

6. Consider the following circuits:



Which circuits above represent a circuit consisting of two light bulbs connected in parallel to the cell?

A. 1and 2

B. 2 and 3.

C. 1and 3

D. 3 and 4

E. 1 and 4

7. The battery in a circuit supplies constant ______________

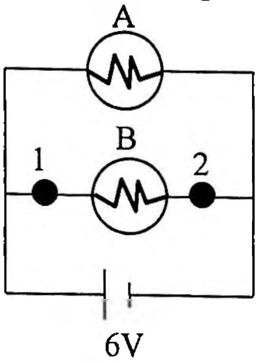
A. electric current.

B. electrical energy.

C. electrical resistance.

D. potential difference.

8. What is the potential difference between points 1 and 2, if bulb A is removed?



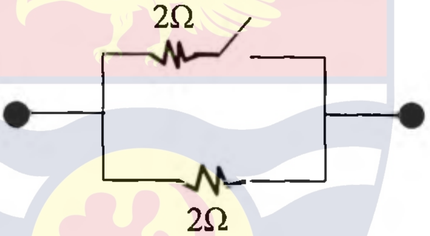
A. 0 V

B. 3 V

C. 6 V

D. 9 V.

9. What is the value of the resistance between the endpoints of the circuit, if the switch is closed?



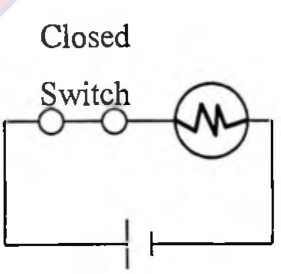
A. 0 Ω

B. 1 Ω.

C. 2 Ω.

D. 4 Ω.

10. What becomes of the resistance of the bulb in the circuit, when the switch is opened?



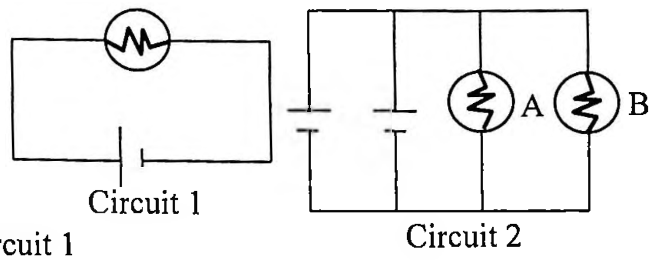
A. The resistance increases.

B. The resistance decreases.

C. The resistance stays the same.

D. The resistance goes to zero.

11. Comparing the brightness of bulb 'A' in circuit 1 to that of bulb 'B' in circuit 2, which bulb is dimmer? [Remember that the bulbs and dry cells are identical]

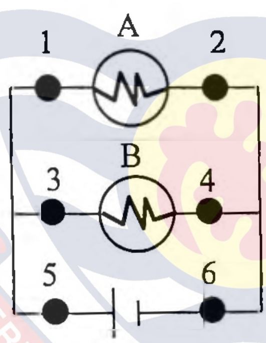


A. Bulb A in circuit 1

B. Bulb B in circuit 2

C. Neither, they are the same.

12. Rank the currents at the points 1, 2, 3, 4, 5 and 6 from highest to the lowest, if the two bulbs are identical.



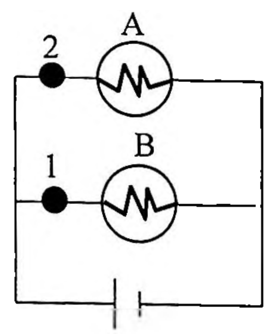
A. 5, 1, 3, 2, 4, 6.

B. 5 = 6, 3 = 4, 1 =2

C. 5 =6, 1 = 2 =3 =4.

D. 1 = 2 = 3 = 4 = 5 = 6.

13. What becomes of the brightness of bulb 'A' and that of bulb 'B' when a wire is connected between points 1 and 2?



A. Decreases

B. Increases

C. Stays the same

D. Bulb A becomes brighter than bulb B.

E. Neither of the bulbs will light.

14. If you double the current from a battery, will the potential difference across that battery be doubled too?

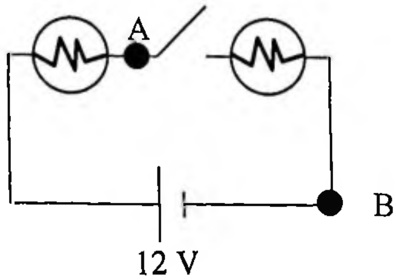
A. Yes, because as you increase the resistance, you automatically increase the potential difference.

B. Yes, because potential difference is directly proportional to the current.

C. No, because as you double the current, you reduce the potential difference by half.

D. No, because the potential difference is a property of the battery.

15. What is the potential difference between points A and B?



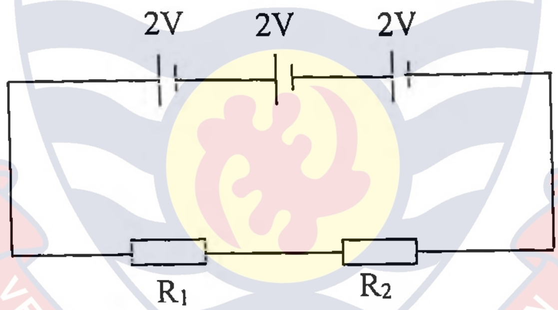
A. 0 V

B. 3 V

C. 6 V

D. 12 V

16. In the circuit diagram, what is the total voltage across the resistor R_1 if that across resistor R_2 is 3V?



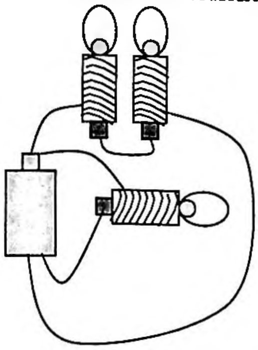
A. 12 V

B. 9 V

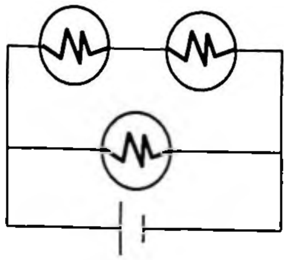
C. 6 V

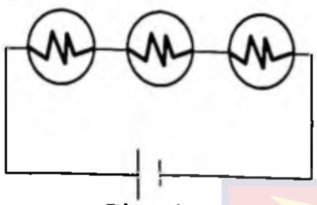
D. 3 V

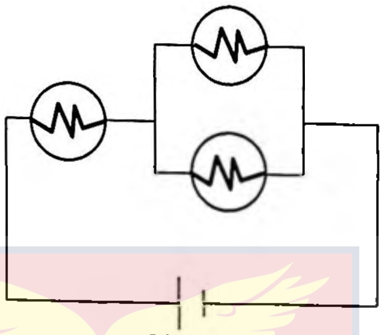
17. Which schematic diagram represents the circuit shown in the figure?

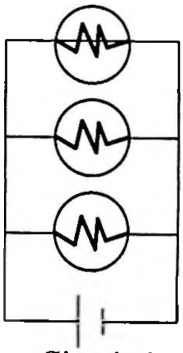


Figure


Circuit 1


Circuit 2


Circuit 3


Circuit 4

A. Circuit 1.

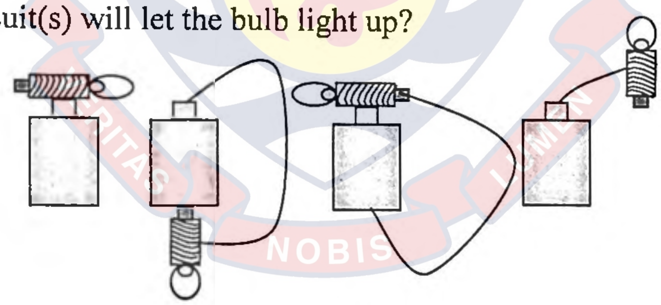
B. Circuit 2.

C. Circuit 3.

D. Circuit 4.

E. None of the above.

18. Which circuit(s) will let the bulb light up?



A. 2

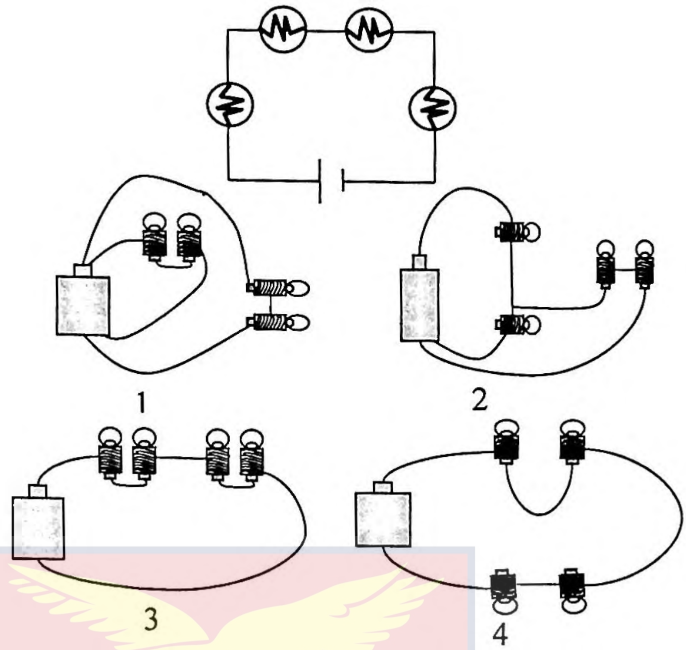
B. 3

C. 4

D. 2 and 3

E. 1 and 4

19. Which circuit(s) represent(s) the schematic diagram shown?



A. 2.

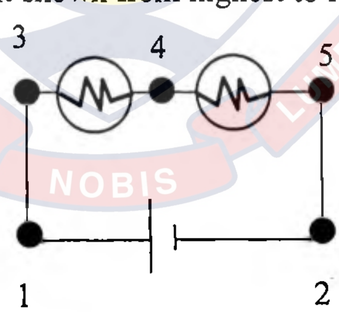
B. 3

C. 4

D. 1 and 2

E. 3 and 4

20. Rank the potential difference between points 1 and 2, points 3 and 4, and points 4 and 5 in the circuit shown from highest to lowest if the bulbs are identical.



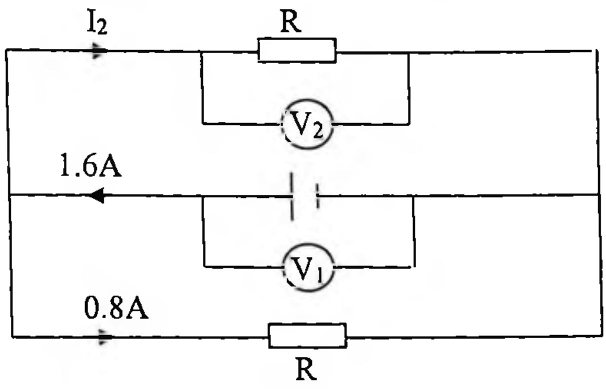
A. (1 and 2); (4 and 5); and (3 and 4).

B. (3 and 4); (4 and 5); (1 and 2).

C. (3 and 4) = (4 and 5); and (1 and 2).

D. (1 and 2); (3 and 4) = (4 and 5).

Use the circuit diagram below to answer questions 21 and 22.



21. What is the value of V_1, if V_2 reads 4V?

A. 4V

B. 3V

C. 2V

D. 1V

22. What is the value of the current I_2?

A. 0.4 A

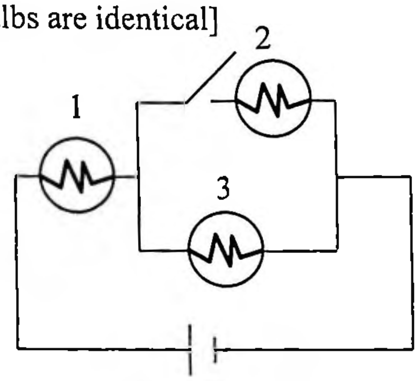
B. 0.6 A

C. 0.8 A

D. 1.0 A

23. What happens to the brightness of bulbs 1 and 3 if the switch is closed?

[Remember that the three bulbs are identical]



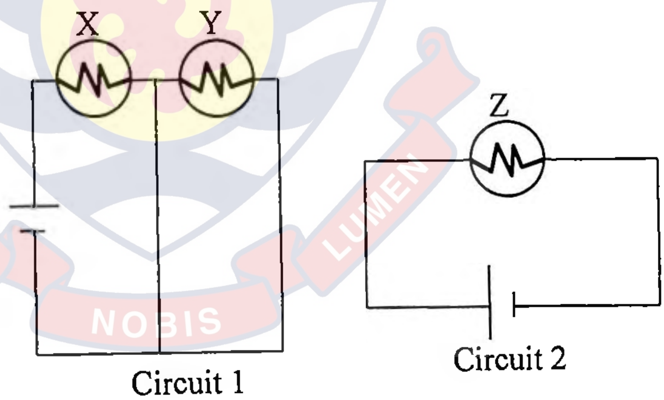
A. 1 and 3 remain the same.

B. 1 is bright and 3 dims.

C. 1 and 3 increase.

D. 1 and 3 decrease.

24. Comparing the brightness of bulbs X and Y in (Circuit 1) to the brightness of bulb Z in (Circuit 2), if the bulbs are identical which bulb or bulbs are the brightest?



A. X

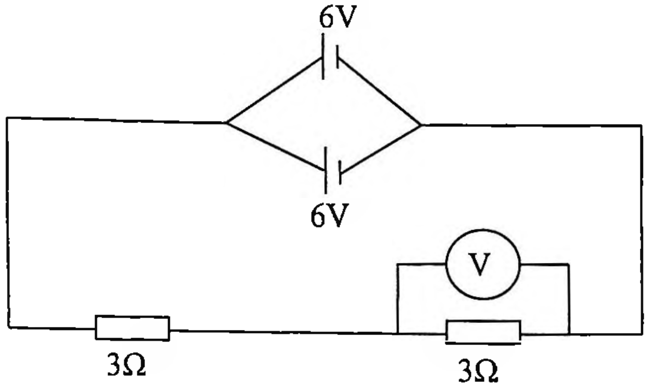
B. Y

C. Z

D. X = Y

E. X = Z

25. In the circuit diagram, what is the effective voltage?



A. 0.33 V

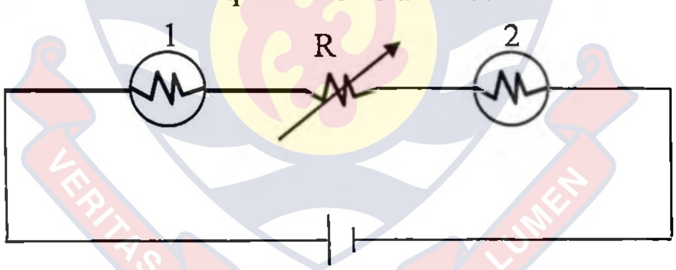
B. 3 V

C. 6 V

D. 9 V

E. 12 V

Use this circuit to answer questions 26 and 27.



26. If the value of the resistor R is decreased, what happens to the brightness of bulb 1?

A. It decreases.

B. It increases

C. It remains unchanged.

27. If the value of the resistor R is increased, what happens to the brightness of bulbs 1 and 2?

   A. 1 stays the same and 2 dims.

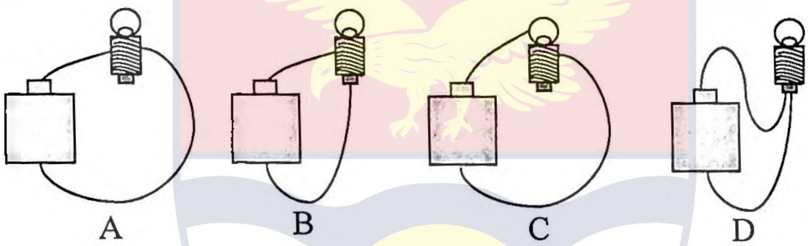
   B. 1 dim and 2 stays the same.

   C. 1 and 2 increase.

   D. 1 and 2 decreases.

   E. 1 and 2 remain the same.

28. Will all the bulbs in the circuits below be of the same brightness?



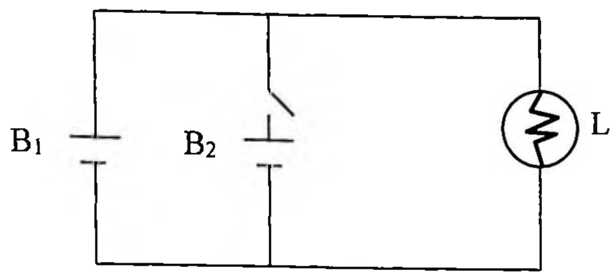
   A. Yes, because all of them have the same type of circuit wiring.

   B. No, only B will light because the connections of A, C and D are not correct.

   C. No, only D will light because D is the only complete circuit.

   D. No, C will not light, but A, B and D will.

29. Two identical dry cells B_1 and B_2 are connected in parallel with the bulb L as shown in the circuit as below. What happens to the current through the bulb when the switch is closed?



A. decreases

B. increases

C. remains the same

D. doubles

30. Assuming all the lights in your home are controlled by one switch. Why would they come on almost instantaneously when switched on?

A. Charges are already in the wires so there is a rapid rearrangement of charges in the circuit when the circuit is complete.

B. When the circuit is complete, charges store energy and release them.

C. Charges in the wire travel very fast.

D. Current is already flowing because circuits in the home are wired parallel.

APPENDIX D

ELECTRIC CIRCUITS CONCEPTION TEST (ECCT)

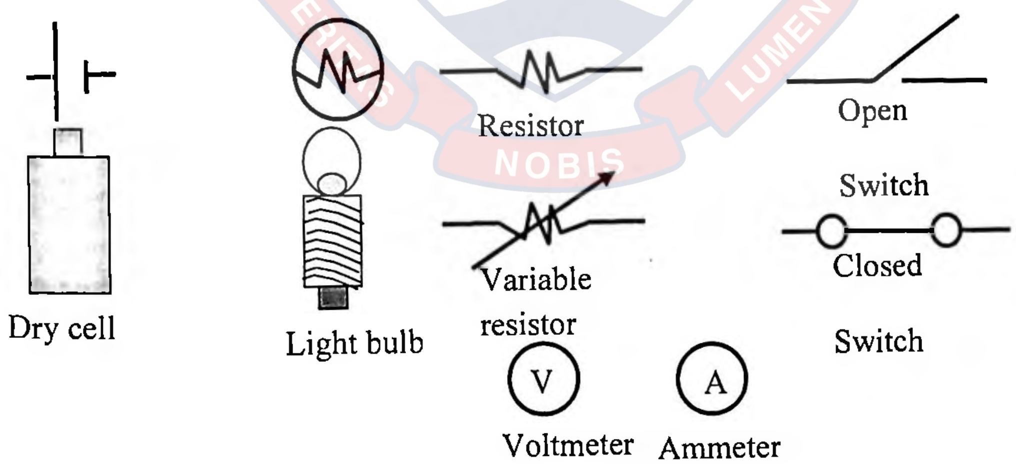
Time Allowed: 1hour

The test consists of nine questions to survey your response about concepts in electric circuits. Please answer all questions and explain your reasoning in the spaces provided for each question. Your responses to the questions are very important.

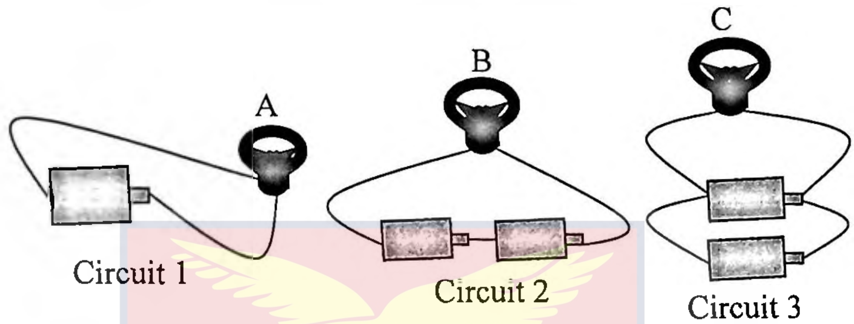
Thank you your cooperation.

ADDITIONAL COMMENTS ABOUT THE TEST

All light bulbs, resistors and dry cells (battery) should be considered identical unless you are told otherwise. The battery is to be assumed as ideal (i. e. with negligible internal resistance). Also, assume the wires have negligible resistance. Below is a key to the symbols used in this test. Study them carefully before you begin the test.



1. Each bulb in the circuits given is identical. In Circuit 2, the second dry cell is connected to the first in series. In Circuit 3, the second dry cell is connected to the first in parallel. After adding the second dry cell to Circuits 2 and 3, arrange the circuits in order of increasing brightness of the bulb. Please choose the correct option and then explain your reasoning.



A. A>B>C

B. B>A>C

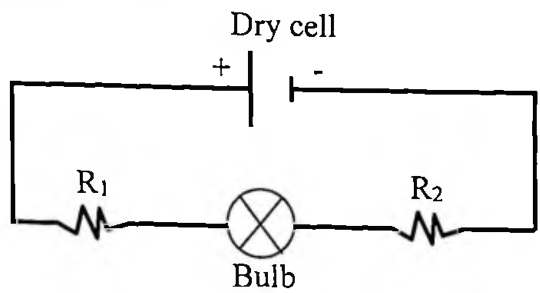
C. B>A=C

D. A=B=C

E. B=C>A

Explain your reasoning:..

2. Consider the following given circuits. What will happen to the brightness of bulb, if the value of resistor R_1 decreases?



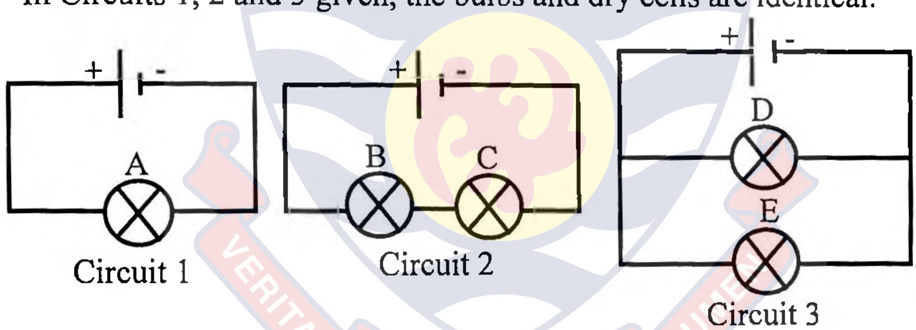
A. Increase

B. Decrease

C. Remain the same

Explain your reasoning: ....

3. In Circuits 1, 2 and 3 given, the bulbs and dry cells are identical.



Arrange the brightness of the bulbs in order of increasing brightness. Please choose the correct option and then explain your reasoning.

A. A>B=C=D=E

B. A=B=C>D=E

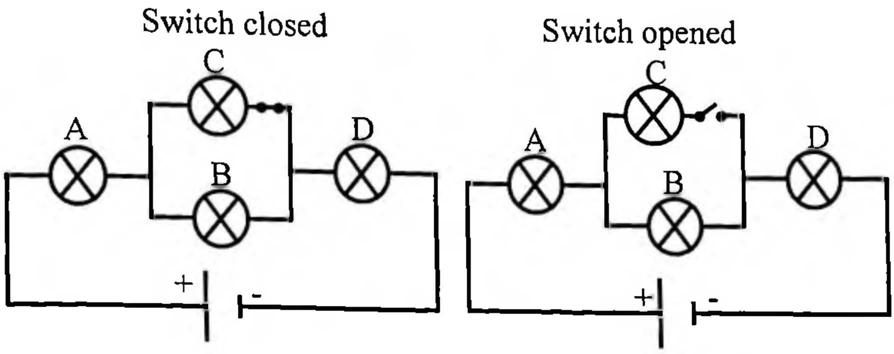
C. A>B=C>D=E

D. A=D=E>B=C

E. A=B>C>D>E

Explain your reasoning:..

In Circuits 1 and 2, the bulbs are identical.



Circuit 1 Circuit 2

Use this information to answer questions 4 and 5

4. In Circuit 1, the switch is closed. Please rank the bulbs in order of increasing brightness. Choose the correct option and then explain your reasoning.

A. A=B=C=D

B. A>B=C>D

C. C>A=D>B

D. A=D>B=C

E. No bulbs give light

Explain your reasoning: ....

5. In Circuit 2, the switch is opened. Please rank the bulbs in order of increasing brightness. Choose the correct option and then explain your reasoning.

A. A>B=C>D

B. A>B=D, C gives no light

C. A=B= C=D

D. A=B=D, C gives no light

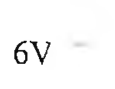
E. No bulbs give light

Explain your reasoning: ....

6. In the given circuit,

two points? Please

reasoning.



A. Between 1 and 2 =

B. Between 1 and 2 =

C. Between 1 and 2 =

D. Between 1 and 2 =

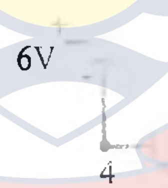
E. Between 1 and 2 = 0

Explain your reasoning: ....

7. In the given circuits, th

differences between the giv

and then explain your reason



A. Between 1 and 2 = 6 Volt, 2 and 3 = 6

B. Between 1 and 2 = 6 Volt, 2 and 3 = 3 Volt,

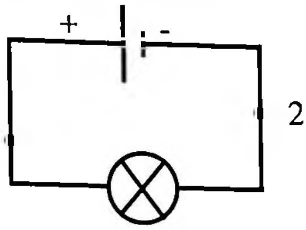
C. Between 1 and 2 = 0 Volt, 2 and 3 = 3 Volt, 3 and

D. Between 1 and 2 = 2 Volt, 2 and 3 = 2 Volt, 3 and 4 =

E. Between 1 and 2 = 0 Volt, 2 and 3 = 3 Volt, 3 and 4 = 3 Volt

Explain your reasoning: ....

8. In the circuit given, what is the current between given points 1 and 2?



Choose the correct the option and then explain your reasoning.

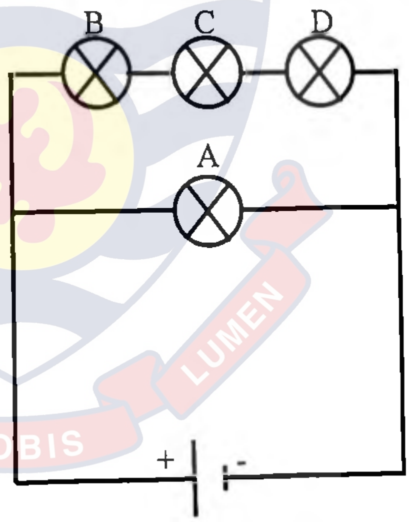
A. 1 > 2

B. 1 = 2

C. 1 < 2

Explain your reasoning: ....

9. In the circuit given, the bulbs are identical. Please rank the bulbs in order of increasing brightness. Choose the correct option and then explain your reasoning.



Circuit 2

A. A=B=C=D

B. A>B=C=D

C. A=B>C>D

D. B=C=D>A

E. A>B>C>D

Explain your reasoning:..

APPENDIX E

GROUP ASSESSMENT OF LOGICAL THINKING (GALT)

Multiple Choice Version

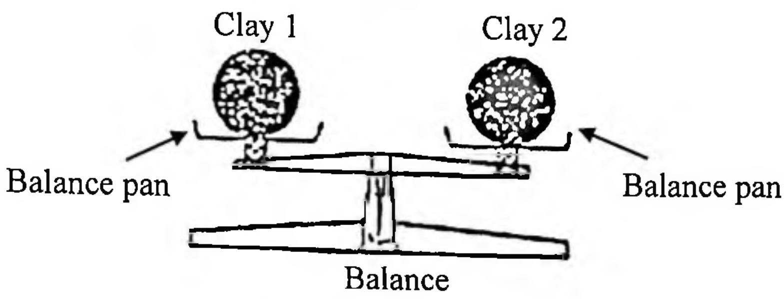
Directions to Students:

This is a test of your ability to apply aspects of scientific reasoning and calculations to analyse a situation to make a prediction or solve a problem. Circle the best option for each item.

Time Allowed: 1 Hour

Age of Student ……………..

1a. Tom has two balls of clay. They are of the same size and shape. When he places them on the balance, they weigh the same.



The balls of clay are removed from the balance pans. Clay 2 is flattened like a pancake.

WHICH OF THESE STATEMENTS IS CORRECT?

A. The pancake-shaped clay weighs more than the ball

B. The two pieces still weigh the same

C. The ball weighs more than the pancake-shaped clay

1b. REASON

A. the flattened piece covers a larger area.

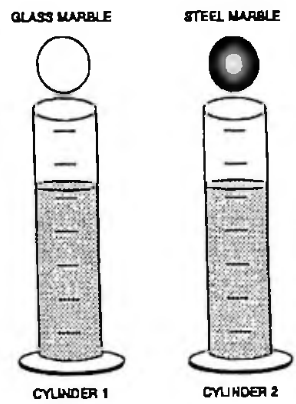
B. the ball pushes down more on one spot.

C. when something is flattened it loses weight.

D. clay has not been added or taken away.

E. when something is flattened it gains weight.

2a. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape. Also shown at the right are two marbles, one of glass and one of steel. The marbles are of the same size but the steel one is much heavier than the glass one. When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. If we put the steel marble into Cylinder 2, the water will rise



A. to the same level as it did in Cylinder 1

B. to a higher level than it did in Cylinder 1

C. to a lower level than it did in Cylinder 1

2b. REASON

A. the steel marble will sink faster.

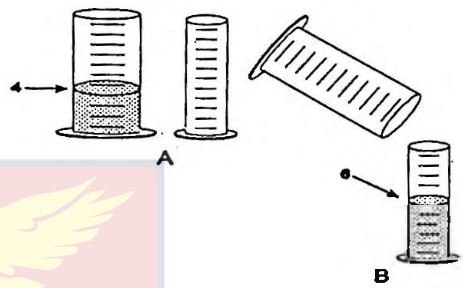
B. the marbles are made of different materials.

C. the steel marble is heavier than the glass marble.

D. the glass marble creates less pressure.

E. the marbles are the same size.

3a. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B). Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. How high would this water rise if it were poured into the empty narrow cylinder?



A. to 8

B. to 9

C. to 10

D. to 12

E. none of these answers is correct

3b. REASON

A. the answer cannot be determined with the information given.

B. it went up 2 more before, so it will go up 2 more again.

C. it goes up 3 in the narrow for every 2 in the wide.

D. the second cylinder is narrower.

E. for every 2 in the wide it goes up 1 more in the narrow.

4a. Water is now poured into the narrow cylinder (described in Item 3 above) up to the 11th mark. How high would this water rise if it were poured into the empty wide cylinder?

A. to 9

B. to 8

C. to 71/2

D. to 7 1/3

E. none of these answers is correct

4b. REASON

A. the ratios must stay the same.

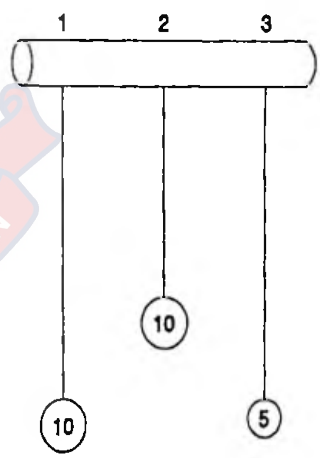
B. one must actually pour the water and observe to find out.

C. the answer cannot be determined with the information given.

D. it was 2 less before so it will be 2 less again.

E. you subtract 2 from the wide for every 3 from the narrow.

5a. The drawing shows three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10-unit weight is attached to the end of String 1. A 10-unit weight is also attached to the end of String 2. A 5-unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed. Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth.



Which strings would you use to find out?

A. only one string

B. all three strings

C. 2 and 3

D. 1 and 3

E. 1 and 2

5b. REASON

A. you must use the longest strings.

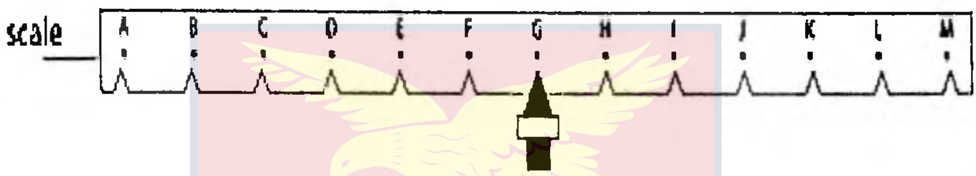
B. you must compare strings with both light and heavy weights.

C. only the lengths differ.

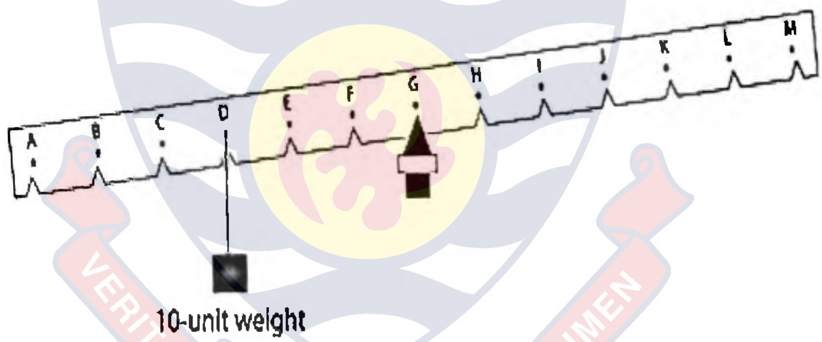
D. to make all possible comparisons.

E. the weights differ.

6a. Joe has a scale like the one below.



When he hangs a 10-unit weight at point D, the scale looks like this:



Where would he hang a 5-unit weight to make the scale balance again?

A. at point J

B. between K and L

C. at point L

D. between L and M

E. at point M

6b. REASON

A. It is half the weight so it should be put at twice the distance.

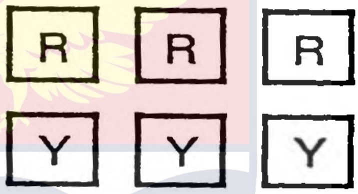
B. The same distance as 10-unit weight, but in the opposite direction.

C. Hang the 5-unit weight further out, to make up its being smaller.

D. All the way at the end gives more power to make the scale balance.

E. The lighter the weight, the further out it should be hung.

7a. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow.



Suppose someone reaches into the bag (without looking) and pulls out one piece. What are the chances that the piece is red?

A. 1 chance out of 6

B. 1 chance out of 3

C. 1 chance out of 2

D. 1 chance out of 1

E. cannot be determined

7b. REASON

A. 3 out of 6 pieces are red.

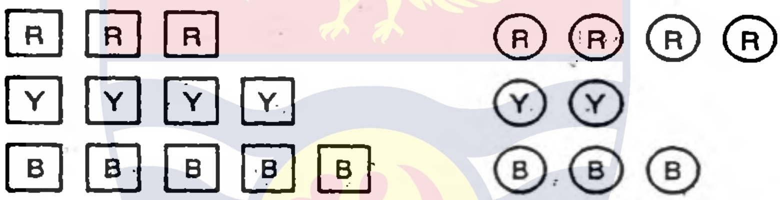
B. there is no way to tell which piece will be picked.

C. only 1 piece of the 6 in the bag is picked.

D. all 6 pieces are identical in size and shape.

E. only 1 red piece can be picked out of the 3 red pieces.

8a. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about.



Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece.

What is the chance that the piece is a red round or blue round?

A. cannot be determined

B. 1 out of 3 chances

C. 1 out of 21 chances

D. 15 out of 21 chances

E. 1 chance out of 2

8b. REASON

A. 1 of the 2 shapes is round.

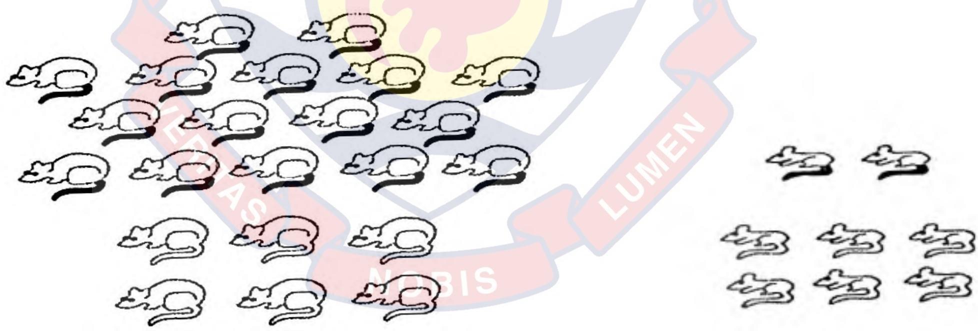
B. 15 of the 21 pieces are red or blue.

C. there is no way to tell which piece will be picked.

D. only 1 of the 21 pieces is picked out of the bag.

E. 1 of every 3 pieces is a red or blue round piece.

9a. Farmer Brown was observing the mice that live in his field. He discovered that all of the mice were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



Does there appear to be a pattern or link between the size of the mice and the color of their tails?

A. There appears to be a link

B. There appears not to be a link

C. I cannot make a reasonable guess

9b. REASON

A. there are some of each kind of mouse.

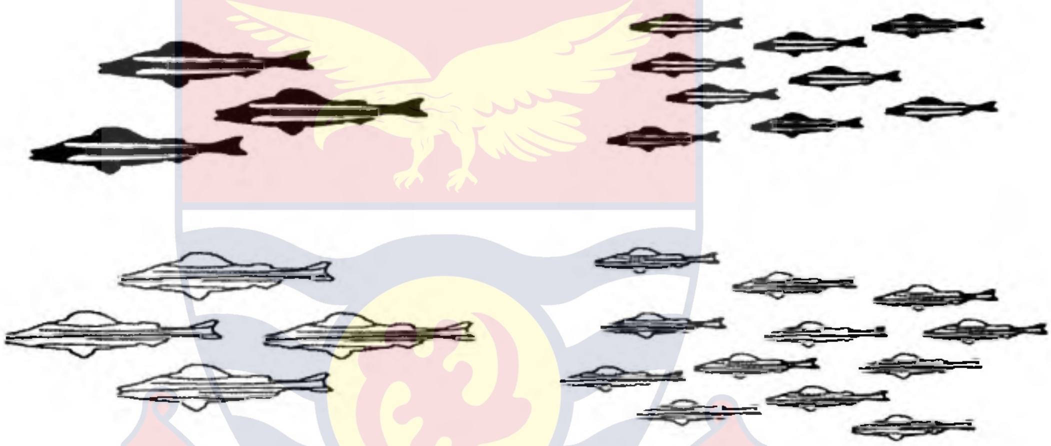
B. there may be a genetic link between mouse size and tail color.

C. there were not enough mice captured.

D. most of the fat mice have black tails while most of the thin mice have white tails.

E. as the mice grew fatter, their tails became darker.

10a. Some of the fish below are big and some are small. Also some of the fish have wide stripes on their sides. Others have narrow stripes.



Is there a relationship between the size of the fish and the kind of stripes it has?

A. There appears to be a relationship

B. There appears not to be a relationship

C. I cannot make a reasonable guess

10b. REASON

A. Big and small fish can have either wide or narrow stripes.

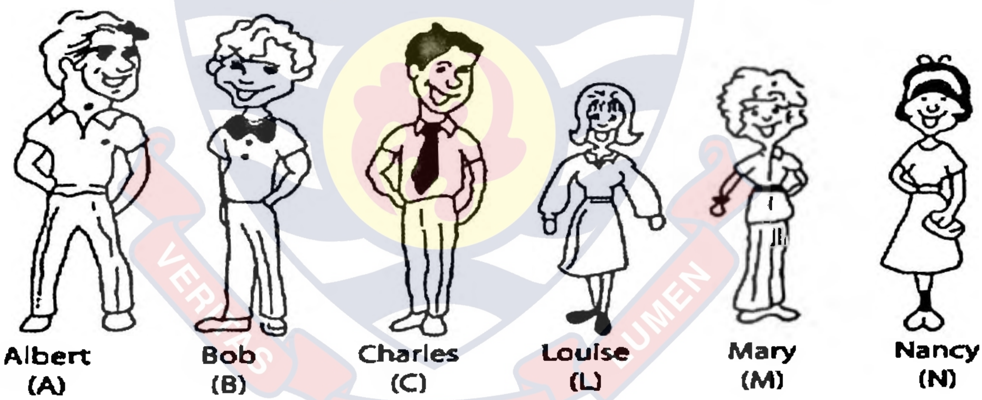
B. 3/7 of the big fish and 9/21 of the small fish have wide stripes.

C. 7 fish are big and 21 are small.

D. Not all big fish have wide stripes and not all small fish have narrow stripes.

E. 12/28 of fish have wide stripes and 16/28 of fish have narrow stripes.

11. After supper, some students decide to go dancing. There are three boys: ALBERT (A), BOB (B), and CHARLES (C), and three girls: LOUISE(L), MARY (M), and NANCY (N).



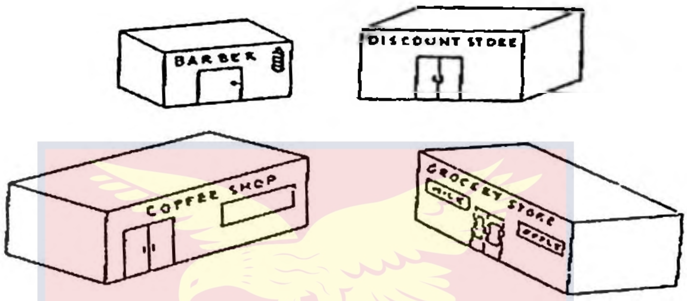
One possible pair of dance partners is A-L, which means ALBERT and LOUISE.

LIST ALL OTHER POSSIBLE COUPLES OF DANCERS

[REMEMBER THAT BOYS DO <u>NOT</u> DANCE WITH BOYS, AND GIRLS DO <u>NOT</u> DANCE WITH GIRLS].

12. In a new shopping centre, 4 stores are going to be placed on the ground floor. A barbering shop (B), a discount store (D), a grocery store (G), and a coffee shop (C) want to locate there.

One possible way that the stores could be arranged in the 4 locations is BDGC which means the barbering shop first, the discount store next, then the grocery store and the coffee shop last.



LIST ALL THE OTHER POSSIBLE WAYS THAT THE STORES CAN BE LINED UP IN THE FOUR LOCATIONS.

APPENDIX F

ANSWERS, DISCRIMINATION AND DIFFICULTY INDICES OF THE ITEMS IN CECAT

	Answer	Right	Wrong	N	P	Q	pq	Upper (U)	Lower (L)	(U-L)/34
1	D	52	73	125	.42	.58	.24	26	10	.47
2	D	56	69	125	.45	.55	.25	21	10	.32
3	C	55	70	125	.44	.56	.25	18	13	.15
4	A	81	44	125	.65	.35	.23	25	21	.12
5	B	82	43	125	.66	.34	.23	26	18	.24
6	C	67	58	125	.54	.46	.25	31	10	.62
7	B	54	71	125	.43	.57	.25	28	5	.68
8	C	75	50	125	.60	.40	.24	27	15	.35
9	B	69	56	125	.55	.45	.25	28	15	.38
10	C	53	72	125	.42	.58	.24	31	1	.88
11	C	50	75	125	.40	.60	.24	16	10	.18
12	C	61	64	125	.49	.51	.25	28	6	.65
13	C	55	70	125	.44	.56	.25	21	11	.29
14	B	77	48	125	.62	.38	.24	31	11	.59
15	D	63	62	125	.50	.50	.25	22	15	.21
16	D	51	74	125	.41	.59	.24	26	7	.56
17	A	84	41	125	.67	.33	.22	28	17	.32
18	D	61	64	125	.49	.51	.25	28	6	.65
19	B	40	85	125	.32	.68	.22	33	1	.94
20	D	52	73	125	.42	.58	.24	25	4	.62
21	A	55	70	125	.44	.56	.25	23	4	.56
22	C	86	39	125	.69	.31	.21	29	16	.38
23	B	67	58	125	.54	.46	.25	24	11	.38
24	E	41	84	125	.33	.67	.22	18	6	.35
25	C	63	62	125	.50	.50	.25	25	7	.53
26	B	49	76	125	.39	.61	.24	16	8	.24
27	D	61	64	125	.49	.51	.25	30	6	.71
28	B	67	58	125	.54	.46	.25	30	9	.62
29	C	49	76	125	.39	.61	.24	13	8	.15
30	C	55	70	125	.44	.56	.25	34	4	.88
					.489	Sum of pq=	7.21			.467

Where

p = proportion of students choosing right option,

q = proportion of students choosing wrong option

Variance (s^2) = 30.344

$$KR-20 = \frac{n}{n-1}\left[1 - \frac{\sum pq}{s^2}\right]$$

$$= \frac{125}{124}\left[1 - \frac{7.21}{30.34}\right]$$

$$= 0.768$$

APPENDIX G

SPSS OUTPUT OF RESULTS OF CRONBACH ALPHA RELIABILITY COEFFICIENT OF ECCT

Case Processing Summary

		N	%
Cases	Valid	112	100.0
	Excluded[a]	0	.0
	Total	112	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.729	9

Item Statistics

	Mean	Std. Deviation	N
Q1	.56	.516	112
Q2	.54	.500	112
Q3	.84	.494	112
Q4	.80	.462	112
Q5	.71	.548	112
Q6	.64	.567	112
Q7	.74	.498	112
Q8	.64	.500	112
Q9	.53	.536	112

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q1	5.45	5.889	.244	.733
Q2	5.46	5.440	.461	.695
Q3	5.17	5.962	.232	.733
Q4	5.21	5.912	.285	.724
Q5	5.30	5.024	.587	.670
Q6	5.37	5.279	.447	.697
Q7	5.27	5.333	.516	.686
Q8	5.37	5.712	.337	.716
Q9	5.48	5.189	.528	.682

APPENDIX H

DISCRIMINATION AND DIFFICULTY INDICES OF THE ITEMS IN GALT

	Right	Wrong	P	Q	pq	Upper (U)	Lower (L)	(U-L)/21
1	56	20	.74	.26	.19	18	11	.33
2	34	42	.45	.55	.25	11	7	.19
3	29	47	.38	.62	.24	20	1	.90
4	39	37	.51	.49	.25	21	2	.90
5	36	40	.47	.53	.25	18	5	.62
6	30	46	.39	.61	.24	10	5	.24
7	46	30	.61	.39	.24	19	4	.71
8	45	31	.59	.41	.24	18	5	.62
9	40	36	.53	.47	.25	21	1	.95
10	32	44	.42	.58	.24	19	1	.86
11	67	9	.88	.12	.10	20	16	.19
12	37	39	.49	.51	.25	20	4	.76
			.538	Sum of pq=	2.74			.606

Where

p = proportion of students choosing right option,

q = proportion of students choosing wrong option

Variance (s^2) = 9.184

$$KR-20 = \frac{n}{n-1}\left[1-\frac{\sum pq}{s^2}\right]$$

$$= \frac{76}{75}\left[1-\frac{2.74}{9.184}\right]$$

$$= 0.711$$

APPENDIX I

LESSON PLANS FOR TEACHING THE CONCEPTS IN ELECTRIC CIRCUITS USING A COMBINATION OF INQUIRY-BASED REAL HANDS-ON AND COMPUTER SIMULATION METHODS

LESSON ONE

TOPIC: Elements of Simple Electric Circuit

DURATION: 70 minutes

RELEVANT PREVIOUS KNOWLEDGE: Students have been using the torchlight bulb, dry cell(s) and connecting wires to light up the bulb.

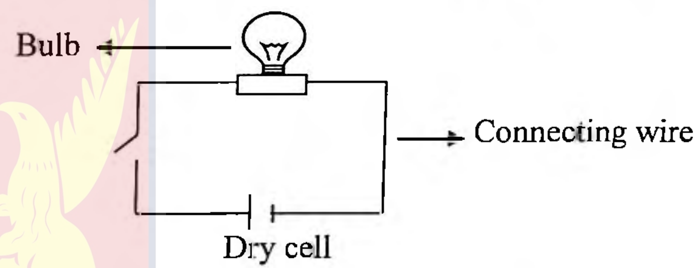
SPECIFIC OBJECTIVES: By the end of the lesson, the student should be able to:

1. state the physical elements of a simple electric circuit.
2. define 'electromotive force', 'potential difference', 'electric current' and 'electric resistance' in his/her own words.

TEACHING/LEARNING MATERIALS: Computer with Circuit Construction Kit (CCK) software installed, a dry cell, a torchlight bulb, key and two connecting wires.

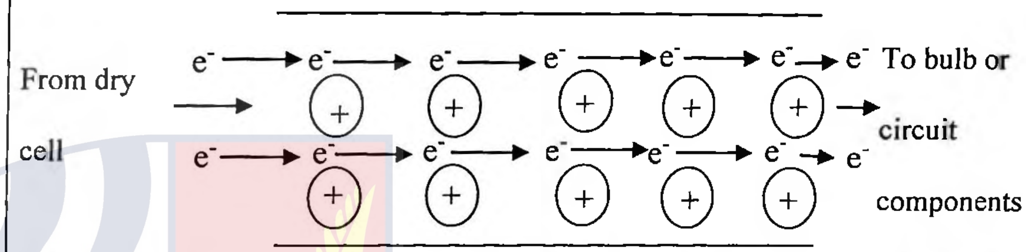
ADVANCED PREPARATION: Teacher prepares the laboratory and gets all teaching and learning materials ready for the lesson and also tries them out to ensure that they can help achieve the desired results.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Exploration Stage (30 minutes)	1. Teacher takes students through the features of the Circuit Construction Kits (CCK) and how to use the various components to construct electric circuits. 2. Teacher asks students (in groups) to use a dry cell, a bulb, a key and connecting wires in the software and find out different ways to light the bulb and also describe how they got the bulb to light. 3. Teacher again gives students a real dry cell, a bulb, key and connecting wires and asked to light the bulb.	1. Students listen and watch while the teacher takes them through the features of CCK and how to use the various components to construct electric circuits. 2. Students in groups try out different ways to get the bulb to light using CCK and describe how they got the bulb to light. 3. Students use the materials provided to light up the bulb.	

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Explanation Stage (25 minutes)	1. Teacher explains to students the symbols used in electric circuits and also defines what constitutes a "simple electric circuit".	1. Students listen and ask questions where necessary.	i. A simple electric circuit consists of a dry cell or series of dry cells connected by copper wires to one or more resistors (bulbs) or other components as shown below:  ii. When the key is closed, the bulb lights up because current flows through the circuit. iii. When the key is opened the bulb does not light up because no current flows through the circuit.

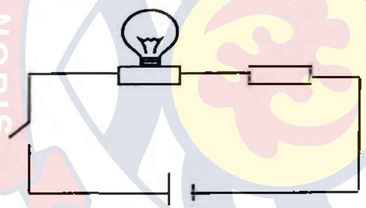
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	2. Teacher helps students to identify the various functions of a dry cell, the bulb, and the connecting wires.	2. Students identify the various functions of the components of a simple circuit.	<u>The Dry Cell</u> A dry cell, either primary or secondary, supplies electrical energy; it has an electromotive force (e.m.f.) which drives electric charges (current) around a closed circuit which sets up a potential difference across the various components. The e.m.f. may be defined as the total work done when the cell transfers a unit positive charge around a circuit. For any given circuit, the greater the e.m.f. the greater the current in the circuit. The unit of e.m.f. is volt (V). The e.m.f. creates an electric potential energy (potential) around a circuit. Conventionally, the direction of current is from the positive terminal to the negative terminal of a cell.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
			Hence the potential is considered to fall from the positive terminal to the negative terminal (i.e., the positive terminal of a cell has a greater potential than the negative terminal). At any two points in the circuit, there exist a potential difference (pd) arising from the fall in potential. Electrical potential energy is analogous to gravitational potential energy (i.e., the higher a body is from the ground the greater the potential energy). Electric potential energy may be defined as the work done in moving a unit charge from one point to another in a circuit. The Connecting Wires The function of connecting wires is to link circuit components together. The conducting wire is made up of positive centres arranged at regular distances from each other and surrounded by free (delocalized) electrons as shown below:

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
			 The e.m.f. drives electrons for the cell which enter the wire and push nearby electrons. Nearby electrons are pushed at the same time towards the other end of the wire. The entry of one electron pushes out one electron at the opposite end of the wire. This is because electrons are free to move between points of different electric potential. Electricity is conducted by the quick movement of electrons through metals (wires).

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
			The amount of electric charge that passes a point in a circuit in one second determines the current. Electric current (I) may be defined as the rate of flow of electric charges around a circuit. Its unit is ampere (A). Mathematically, $Current = \frac{Electric\ charge}{Time} = \frac{Q}{t}$ As the electrons move through a wire their movements get restricted by the positive centres which are continuously vibrating about their fixed positions. This offers resistance to the flow of electric charges compared to the connecting wires in a circuit. Electrical resistance (R) may be defined as the force which opposes the flow of electric charges (current) in a conductor. Its unit is ohm (Ω).

STAGE/STEP/CONTENT ITEM(ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Expansion Stage (15 minutes)	Teacher asks students to do the following exercises individually and compare their answers with group members: 1. Draw a simple electric circuit and label it.	Students do the exercises and construct the	<u>The Bulb</u> The function bulb is to produce illumination. The filament of the torchlight bulb is made of a thin wire which offers more resistance to the flow of charges. Through collision, charges in the filament produce friction which generates heat energy and is converted to light energy to light the bulb.

	2. Define the terms "electromotive force", "electric current", "electric resistance" and "potential difference" in your own words. 3. Calculate the current if 24 coulombs of charge pass through a wire at a steady rate for 4 seconds. 4. Construct the simple circuit below using the CCK 	simple circuit using the CCK	

REMARKS:

REFERENCES:

Cutnell, J. D., & Johnson, K. W. (2007). *Physics* (7th ed.). New Jersey: John Wiley & Sons, Inc.

Serway, R. A., & Beichner, R. J. (2000). *Physics for Scientist and Engineers* (5th ed.). New York: Saunders College Publishing.

Walker, J. (2008). *Fundamentals of physics* (8th ed.). New Jersey: John Wiley & Sons, Inc.

LESSON TWO

TOPIC: Ohm's Law

DURATION: 70 minutes.

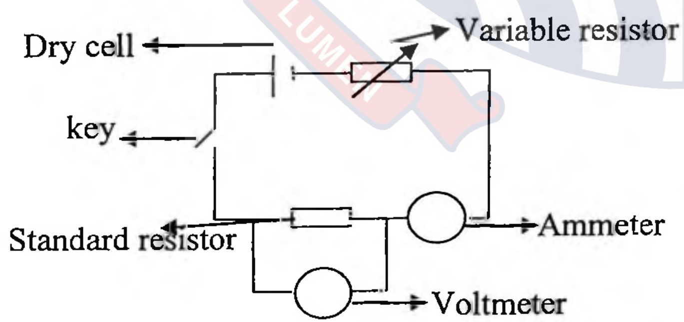
RELEVANT PREVIOUS KNOWLEDGE: Students can set up simple electric circuits and also define the terms "electromotive force", "current", "potential difference" and "resistance".

SPECIFIC OBJECTIVES: By the end of the lesson, the student should be able to:

1. state Ohm's law correctly.
2. perform experiments to verify Ohm's law.

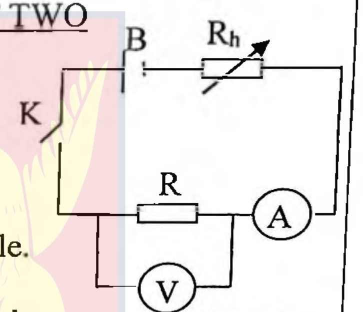
TEACHING/LEARNING MATERIALS: Computer with Circuit Construction Kit (CCK) software installed, a power supply, rheostat, key, ammeter, voltmeter, a standard resistor and connecting wires.

ADVANCED PREPARATION: Teacher prepares the laboratory and gets all teaching and learning materials ready for the lesson and also tries them out to ensure that they can help achieve the desired results.

STAGE/STEP/ CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Exploration Stage (40 minutes)	1. Teacher gives students the instructional sheets containing the steps to be followed and explains to students that the experiment is about finding the relationship between" current" and the "potential difference". 2. Teacher guides students to follow the instructions below to perform the experiment using the CCK. <u>INSTRUCTION SHEET ONE</u> 	1. Students read through the instructions carefully acquaint themselves with the experiments they are about to perform. 2. Students in their groups follow the instructions to perform the experiment using the CCK.	

STAGE/STEP/ CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	a. Construct the circuit as shown using the CCK. b. Change the voltage of the dry cell to 1.5 V, the variable resistor, R_h to 2.0 Ω, and the standard resistor, R to 2.0 Ω by right clicking on each component and show the values. c. Close the key, K and record the reading on the voltmeter, V and ammeter, A. d. Change the resistance of R_h for values of 4.0 Ω, 6.0 Ω, 8.0 Ω and 10.0 Ω and tabulate the results as shown in the table below:		

<table>
<tr><th>STAGE/STEP/CONTENT
ITEM (ESTIMATED TIME)</th><th>TEACHER ACTIVITY</th><th>STUDENT
ACTIVITY</th><th>KEY
IDEAS</th></tr>
<tr><td></td><td>
<table>
<tr><th>R_h/ Ω</th><th>V/V</th><th>I/A</th><th>$\frac{V}{I}$/Ω</th></tr>
<tr><td>2.0</td><td></td><td></td><td></td></tr>
<tr><td>4.0</td><td></td><td></td><td></td></tr>
<tr><td>6.0</td><td></td><td></td><td></td></tr>
<tr><td>8.0</td><td></td><td></td><td></td></tr>
<tr><td>10.0</td><td></td><td></td><td></td></tr>
</table>
e. Evaluate the ratio of V and I.
f. Plot a graph of V on the vertical axis against I on the horizontal axis.
g. Determine the slope of the graph.
h. Compare the value of the slope to the results for the ratio of V and I from the table.
i. What conclusions can you draw from the experiment?
</td><td></td><td></td></tr>
</table>

STAGE/STEP/CONTENT ITEM(ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	3. Teacher guides students to follow the instructions below to perform the experiment using the real components. INSTRUCTION SHEET TWO  a. Connect the circuit as shown. b. Set the rheostat R_h, so that it is as large as possible. c. Close the key K, and record the readings on the voltmeter and ammeter as V_o and I_o respectively. d. Adjust the rheostat to a voltmeter reading of 0.2 V and record the corresponding ammeter reading. e. Repeat the procedure for values of 0.4 V, 0.6 V, 0.8 V and 1 V and tabulate the results as shown on the table below:	3 Students in their groups follow the instructions to perform the experiment using the real components.	

<table>
<tr><th>STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)</th><th>TEACHER ACTIVITY</th><th>STUDENT ACTIVITY</th><th>KEY IDEAS</th></tr>
<tr><td></td><td>V_o= I_o=

<table>
<tr><th>V(V)</th><th>I(A)</th><th>V/I (Ω)</th></tr>
<tr><td>0.2</td><td></td><td></td></tr>
<tr><td>0.4</td><td></td><td></td></tr>
<tr><td>0.6</td><td></td><td></td></tr>
<tr><td>0.8</td><td></td><td></td></tr>
<tr><td>1.0</td><td></td><td></td></tr>
</table>

f. Evaluate the ratio of V and I.
g. Plot a graph of V on the vertical axis against I on the horizontal axis.
h. Determine the slope of the graph.
i. Compare the value of the slope to the results for the ratio of V and I from the table.
j. What conclusions can you draw from the experiment?</td><td></td><td></td></tr>
</table>

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Explanation Stage (15 minutes)	Teacher through discussion with students derives Ohm's law from the experiments performed.	Students through discussion with teacher derive Ohm's law from the experiments performed.	1. Ohm's law states that at constant temperature the current passing through a wire is directly proportional to the potential difference between the ends of the wire. 2. Mathematically, the law is given as $V \propto I, \Rightarrow V = IR, \frac{V}{I} = R$ where R is the constant of proportionality and called "electrical resistance". This means electrical resistance in inversely proportional to electric current.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Expansion Stage (15 minutes)	Teacher asks students do the following exercises: 1. State Ohm's law correctly. 2. With the aid of a diagram, describe an experiment to verify Ohm's law. 3. For a cell with a voltage of 1.5 V producing a current of 0.5 A, what is the resistance of the connecting wire?	Students do the exercises individually and compare their answers with group members.	

REMARKS:

REFERENCES:

Cutnell, J. D., & Johnson, K. W. (2007). *Physics* (7th ed.). New Jersey: John Wiley & Sons, Inc.

Serway, R. A., & Beichner, R. J. (2000). *Physics for Scientist and Engineers* (5th ed.). New York: Saunders College Publishing.

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LESSON THREE

TOPIC: Cells Connected in series

DURATION: 70 minutes

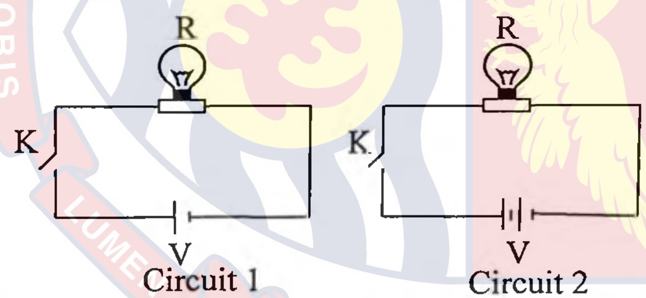
RELEVANT PREVIOUS KNOWLEDGE: Students can connect up simple electric circuits and also apply Ohm's law in various calculation problems.

SPECIFIC OBJECTIVES: By the end of the lesson, the student should be able to:

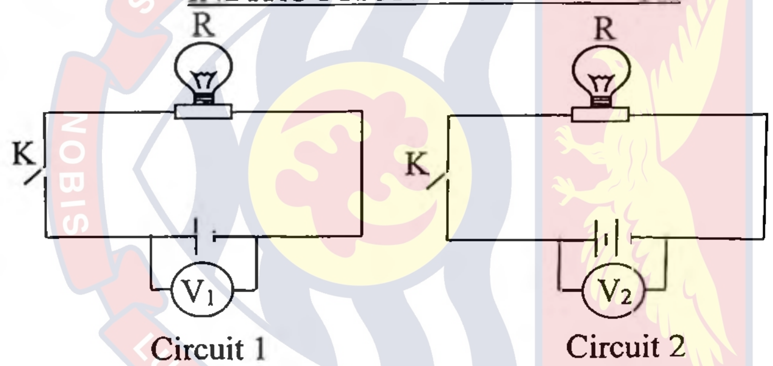
1. explain that the more the number of cells connected in series, the brighter the lighted bulb in the circuit.
2. show that the total voltage of a number of cells connected in series equals the algebraic sum of the voltages of the individual cells.

TEACHING/LEARNING MATERIALS: Computer with Circuit Construction Kit (CCK) software installed, three dry cells, a bulb, key and connecting wires.

ADVANCED PREPARATION: Teacher prepares the laboratory and gets all teaching and learning materials ready for the lesson and also tries them out to ensure that they can help achieve the desired results.

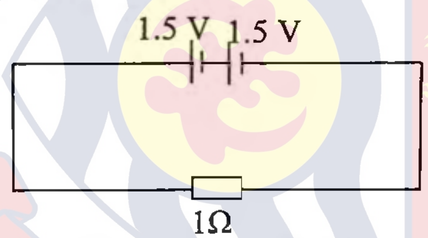
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Exploration Stage (40 minutes)	1. Teacher gives activity sheets to students and guides students in groups to perform the activities on the sheet using the CCK and also repeat the activity using real circuit components. <u>INSTRUCTIONAL SHEET THREE</u> a. Using the materials provided, set up Circuit 1.  b. Predict what you expect about the brightness of bulb R if one more identical dry cell is added to the circuit (like as in Circuit 2). Explain your response.	1. Students in their groups read through the instructions on the activity sheet carefully and follow it to perform the activities using the CCK and also with real circuit components.	

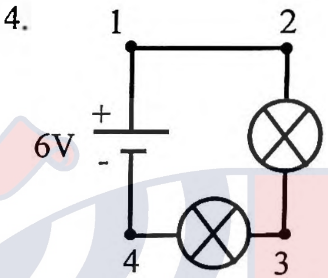
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	c. Discuss your predictions and reasons among yourselves in the group. d. Using your materials, set up Circuit 2. e. What did you observe in the brightness of the bulb in Circuit 2? f. Had your observation confirmed your prediction? Yes/No g. Which circuit had the brightest bulb, Circuit 1 or Circuit 2? h. Why did it turn up so? i. What conclusion can you give for this observation? j. What do you predict will happen to the brightness of the bulb if more identical dry cells were added to Circuit 2? k. Try this out. What did you observe? l. How do we term a circuit that contains dry cells arranged like as in Circuit 2?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	2. Teacher gives students instructional sheet four and asks them to perform the activities using the CCK and also repeat it using real circuit components. INSTRUCTIONAL SHEET FOUR  a. Suppose voltmeter V_1 in Circuit 1 shows a reading of 1.5 V, what will be the reading on voltmeter V_2 in Circuit 2 if the dry cells are identical? V = ...V. Explain your response.	2 Students in their groups read through the instructions on the sheet and perform the activities first using the CCK and also with real circuit components.	

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	b. Discuss your predictions and reasons among yourselves. c. Using the materials provided, set up Circuits 1 and 2 as shown one after the other and note the readings on each voltmeter. V_1 = …….V V_2 = ………..V d. Are there any differences between your response (in Step 1) and experimental results (in Step 3)? Yes/No. Explain your response. e. What will be the reading on the voltmeter if three identical dry cells are connected in series in a circuit? V_3 =………..V. f. What conclusions can you draw about the voltage of dry cells connected in series in a circuit?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Explanation Stage (15 minutes)	Teacher summaries all that has been done in the two activities to students.	Students listen and ask questions where necessary.	1. A group of dry cells connected together is called a battery. 2. Dry cells connected end to end consecutively to each other (as shown) constitute a series connection of cells.  3. The more the number of cells connected in series, the brighter the bulb connected in the circuit will light up. 4. The effective voltage of a number of dry cells in series equals the algebraic sum of the voltages. $V_T = V_1 + V_2 + V_3 + \ldots\ldots\ldots + Vn$

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Expansion Stage (15 minutes)	Teacher asks students do the following exercises: 1. Two dry cells, each having an e.m.f. of 1.5 V, are connected in series as shown below. Find (a). the effective e.m.f. of the cells. (b). the current when the cells are connected to a 1 Ω resistor.  2. Six cells, each having an e.m.f. of 2 V are connected in series with an ammeter of negligible resistance and a 1.4 Ω resistor. (a). Draw the corresponding circuit diagram. (b). Calculate the combined e.m.f. of the dry cells.	Students do the exercises individually and compare their answers with members in their groups.	

	3. Construct the circuit below using both CCK and real circuit components and measure the voltage between 1 and 2, 2 and 3, 3 and 4. 		

REMARKS:

REFERENCES:

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Serway, R. A., & Beichner, R. J. (2000). *Physics for Scientist and Engineers* (5th ed.). New York: Saunders College Publishing.

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LESSON FOUR

TOPIC: Cells Connected in Parallel

DURATION: 70 minutes

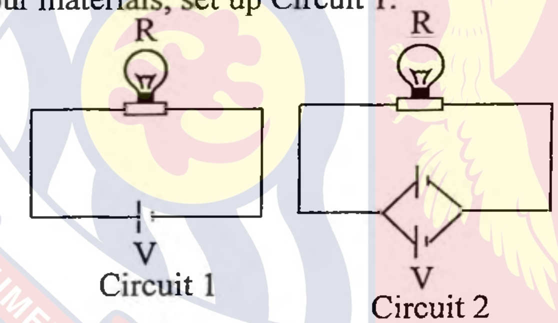
RELEVANT PREVIOUS KNOWLEDGE: Students are familiar with circuit diagrams and circuit connections.

SPECIFIC OBJECTIVES: By the end of the lesson, the student should be able to:

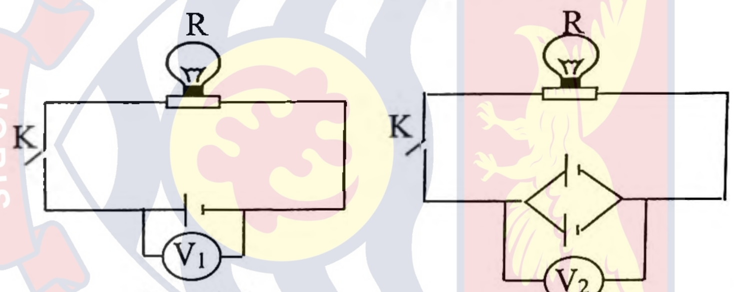
1. explain that a number of identical dry cells connected in parallel does not increase the brightness of a bulb connected in series to it in a circuit.
2. show that the effective voltage of a number of similar cells connected in parallel equals the voltage of one cell.

TEACHING/LEARNING MATERIALS: Computer with Circuit Construction Kit (CCK) software installed, three dry cells, a bulb, key and connecting wires.

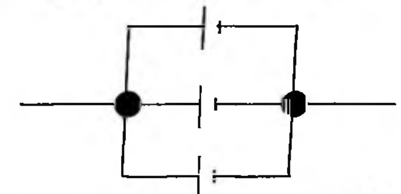
ADVANCED PREPARATION: Teacher prepares the laboratory and gets all teaching and learning materials ready for the lesson and also tries them out to ensure that they can help achieve the desired results.

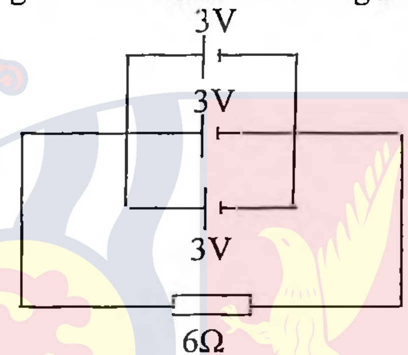
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Exploration Stage (40 minutes)	1. Teacher gives activity sheets to students and guides students in groups to perform the activities on the sheet using the CCK and also repeat the activity using real circuit components. <u>INSTRUCTIONAL SHEET FIVE</u> a. Using your materials, set up Circuit 1.  b. Predict what you expect about the brightness of bulb R should one more identical dry cell be added to the circuit (as in Circuit 2). Explain your response.	1. Students in their groups read through the instructions on the activity sheet carefully and follow it to perform the activities using the CCK and also with real circuit components.	

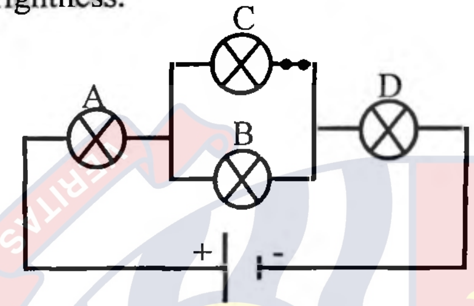
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	c. Discuss your predictions and reasons among yourselves. d. Using your materials, set up Circuit 2. e. What did you observe in the brightness of the bulb in Circuit 2? f. Had your observation confirmed your prediction? Yes/No. g. Which circuit had the brightest bulb, Circuit 1 or Circuit 2? h. Why is this so? i. What conclusion can you give for this observation? j. What do you predict will happen to the brightness of the bulb if more identical dry cells are added to Circuit 2? k. Try this out. What did you observe? l. How do we call a circuit that contains dry cells arranged like in Circuit 2?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	2. Teacher gives students instructional sheet six and asks them to perform the activities using the CCK and also repeat it using real circuit components. <u>INSTRUCTIONAL SHEET SIX</u>  Circuit 1 Circuit 2 a. Suppose voltmeter V_1 in circuit 1 shows a reading of 1.5V, what will be the reading on voltmeter V_2 in Circuit 2? V_2 = ……….V. Explain your response. b. Discuss your predictions and reasons among yourselves.	2 Students in their groups read through the instructions on the sheet and perform the activities first using the CCK and also with real circuit components.	

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	c. Using the materials provided, set up Circuit 1 and 2 as shown, one after the other. Close the key and note the readings on each voltmeter. V_1 = …….V V_2 = ………..V d. Are there any differences between your response (in Step 1) and the experimental results (in Step 3)? Yes/No? Explain your response. e. What will be the reading on the voltmeter if three identical dry cells are connected in parallel? V_3 =……….V. f. What conclusion can you draw about the voltage of the identical dry cells connected in parallel?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Explanation Stage (15 minutes)	Teacher summaries all that has been done in the two activities to students.	Students listen and ask questions where necessary	1. Dry cells connected side by side with their corresponding ends joined together at their respective common points are said to form a parallel connection of cells.  2. The meeting point of three or more wires in an electrical network is called a junction. 3. A number of identical dry cells connected in parallel in a circuit does not increase the brightness of the bulb connected to them (i.e., the brightness remains the same). 4. The effective voltage of a number of similar cells connected in parallel equals the voltage of one of the cells. $V_T = V_1 = V_2 = V_3 = \ldots V_n$ where V_T = Effective/Total/combined voltage.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Expansion Stage (15 minutes)	Teacher asks students do the following exercises: 1. Calculate the effective voltage and the current flowing in the circuit diagram shown.  2. Two dry cells each having an e.m.f. of 1.5 V are connected in parallel in a circuit. Find (a). the effective e.m.f. of the cells. (b). the current when the cells are connected to a 1 Ω resistor.	Students do the exercises individually and compare their answers with group members.	

	3. Construct the circuit below using both CCK and real circuit components and rank the bulbs in order of increasing brightness.  Circuit 1		

REMARKS:

REFERENCES:

Cutnell, J. D., & Johnson, K. W. (2007). *Physics* (7th ed.). New Jersey: John Wiley & Sons, Inc.

Serway, R. A., & Beichner, R. J. (2000). *Physics for Scientist and Engineers* (5th ed.). New York: Saunders College Publishing.

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LESSON FIVE

TOPIC: Resistors Connected in Series

Duration: 120 minutes

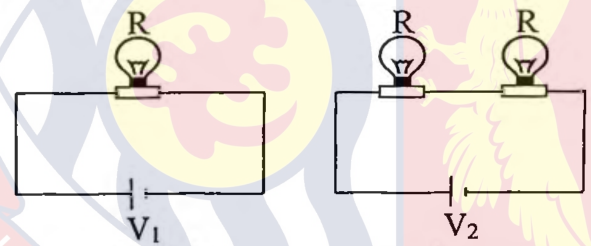
RELEVANT PREVIOUS KNOWLEDGE: Students are familiar with series and parallel connections of dry cells.

SPECIFIC OBJECTIVES: By the end of the lesson, the student should be able to:

1. explain that two or more identical bulbs connected in series to a dry cell produce a dimmer light than one of them connected to the same.
2. explain correctly the following:
    a. the source voltage is shared equally between resistors of similar resistances.
    b. the source voltage is shared proportionally by unequal resistors.
3. deduce the general relation for resistors connected in series.

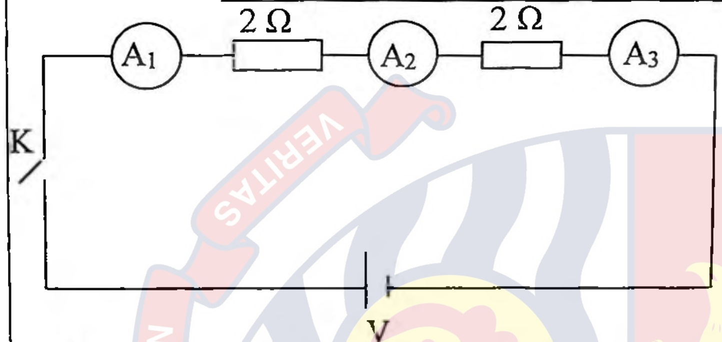
TEACHING/LEARNING MATERIALS: Computer with Circuit Construction Kit (CCK) software installed, dry cells or power supply, three bulbs, key, voltmeters, two 2 Ω resistors, a 3 Ω resistor and connecting wires.

ADVANCED PREPARATION: Teacher prepares the laboratory and gets all teaching and learning materials ready for the lesson and also tries them out to ensure that they can help achieve the desired results.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Exploration Stage (75 minutes)	1. Teacher gives activity sheets to students and guides students in groups to perform the activities on the sheet using the CCK and also repeat the activity using real circuit components. INSTRUCTIONAL SHEET SEVEN a. Using your materials, set up Circuit 1.  Circuit 1 Circuit 2 b. Predict what you expect about the brightness of bulb R if one more identical bulb is added to the circuit (as in Circuit 2). Explain your response.	1. Students in their groups read through the instructions on the activity sheet carefully and follow it to perform the activities using the CCK and also with real circuit components.	

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	c. Discuss your predictions and reasons among yourselves. d. Using your materials, set up Circuit 2. e. What did you observe in the brightness of the bulbs in Circuit 2? f. Had your observation confirmed your prediction? Yes/No. g. Which circuit had the brightest bulb, Circuit 1 or Circuit 2? h. Why is this so? i. What conclusion can you give for this observation? j. What will happen should you unscrew one bulb in Circuit 2? k. Try this out. l. What did you see and why was this so? m. What will happen to the brightness of the bulbs if one more identical bulb should be added to those in Circuit 2?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	n Try the set up. What did you observe? o Suppose you had a string of Christmas tree lights connected like in circuit 2, what would happen to the bulbs when one of the bulbs is unscrewed off? p How do we call a circuit that contains dry cells arranged like in Circuit 2?		
	2. Teacher gives students instructional sheet eight and asks them to perform the activities using the CCK and also repeat it using real circuit components.	2 Students read through the instructions on the sheet and perform the activities first using the CCK and also with real circuit components.	

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	INSTRUCTIONAL SHEET EIGHT  a. In the circuit above, suppose ammeter A_1 shows a reading of 0.06 A. Choose from the alternatives below the correct answer for the current measurement of ammeter A_2 and ammeter A_3. A. $A_2 = 0.05$ A ; $A_3 = 0.04$ A. B. $A_2 = 0.06$ A ; $A_3 = 0.05$ A. C. $A_2 = 0.06$ A ; $A_3 = 0.06$ A. D. $A_2 = 0.07$ A ; $A_3 = 0.08$ A		

Explain your response.

b. Discuss your predictions and reasons among yourselves.

c. Using the materials, set up the circuit as shown in the figure above.

d. Close the key and note down the value of the current passing through each ammeter in turns.

A_1 = ……A A_2 = ……A A_3 = ……A

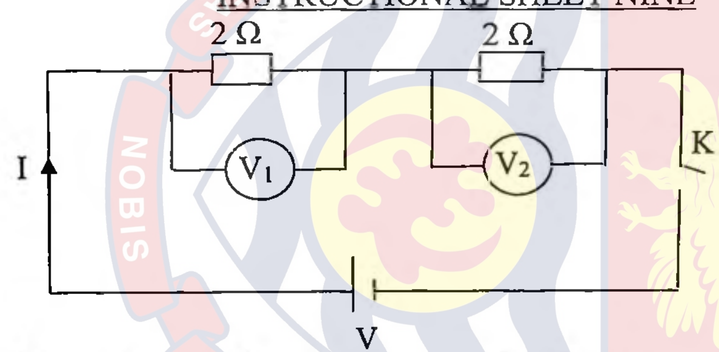
e. Are there any differences between your response (in step 1) and experimental results (in step 4)? Yes/No?

f. Replace the second 2Ω resistor with a 3Ω resistor, and note the ammeter readings in turns.

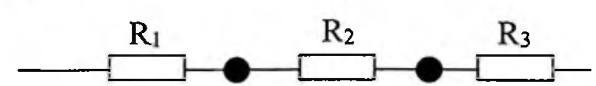
A_1= ……A A_2 = ……A A_3 = ……A

g. Are there any differences between the results in Step 4 and results in Step 6? Yes/No.

h. What conclusions can you draw from the experiment?

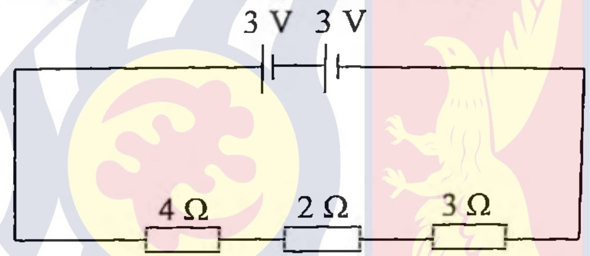
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	3 Teacher gives students instructional sheet nine and asks them to perform the activities using the CCK and also repeat it using real circuit components. INSTRUCTIONAL SHEET NINE  a. In the circuit, will the reading on voltmeter V_1 be the same or different from the reading on voltmeter V_2? Explain your response. b. Discuss your predictions and reasons among yourselves.	3. Students in their groups read through the instructions on the sheet and perform the activities first using the CCK and also with real circuit components.	.

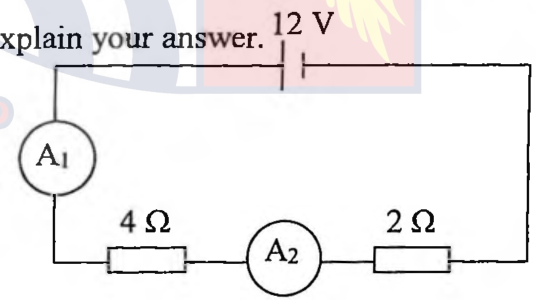
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	c. Using the materials, set up the circuit as shown in the figure above. d. Close the key and note down the readings on each voltmeter in turns. $V_1 = \ldots\ldots V$ $V_2 = \ldots\ldots V$ e. Are there any differences between your response (in Step 1) and experimental results (in Step 4)? Yes/No f. Replace the second 2 Ω resistor with a 3 Ω resistor, and note the voltmeter readings in turns. $V_1 = \ldots\ldots V$ $V_2 = \ldots\ldots V$ g. Are there any differences between the results in step 4 and the results in step 6? Yes/No h. What conclusions can you draw about the voltage across the resistors?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Explanation Stage (30 minutes)	Teacher summaries all that has been done in the three activities to students.	Students listen and ask questions where necessary.	1. Two or more identical bulbs connected in series to a dry cell produce a dimmer light than one of them connected to the same source because the source voltage will be shared among the bulbs. 2. When one of the bulbs is unscrewed, all other bulbs will go off because the circuit will be opened. 3. The arrangement whereby resistors or bulbs are connected end to end consecutively so that the same current flows through each is called series connection of resistors as shown below: 

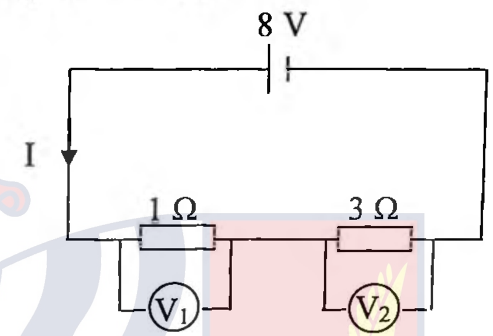
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
			4. The same current flow through resistors connected in series in a given circuit. 5. The algebraic sum of the potential differences (or voltages) across resistors connected in series in a circuit is equal to the effective voltage or source voltage. 6. The effective voltage in a series circuit is shared equally across resistors of similar resistances. 7. The effective voltage in a series circuit is shared proportionally across unequal resistors. 8. The effective voltage across a single resistor in a circuit is that of the source voltage.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
			9. From activity 2 and 3, it can be seen that for any series connection, the current flowing through the resistors is the same whiles the voltages through each resistor is different. From Ohm's law, we get $V_1 = IR_1$ and $V_2 = IR_2$ But the total voltage in the circuit is given by $V = V_1 + V_2$ Substituting equation 1 and 2 into 3, we get $IR = IR_1 + IR_2$ $IR = I(R_1 + R_2)$ $\therefore R = R_1 + R_2$ Generally, if there are two or more resistors in series, the effective or combined resistance (R_T) can be given as $R_T = R_1 + R_2 + R_3 + ...R_N$

<table>
<tr><th>STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)</th><th>TEACHER ACTIVITY</th><th>STUDENT ACTIVITY</th><th>KEY IDEAS</th></tr>
<tr><td>Expansion Stage
(25 minutes)</td><td>Teacher asks students do the following exercises:
1. In the circuit diagram below, what is: (a) the effective voltage of the cells? (b) the effective resistance of the circuit? (c) the current in the circuit? (d) the direction of current in the circuit?


2. In the circuit diagram below, ammeter A_1 reads 2 A. What is the reading of ammeter A_2? Explain your answer.

</td><td>Students do the exercises individually and compare their answers with group members.</td><td></td></tr>
</table>

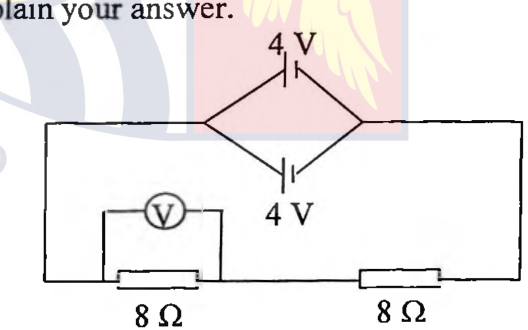
3. In the circuit diagram below, what are the readings of voltmeter V_1 and V_2? Explain your answers.



4. In the circuit below

a. What is the effective voltage?

b. What will be the reading of the voltmeter V shown in the diagram? Explain your answer.



REMARKS:

REFERENCES:

Cutnell, J. D., & Johnson, K. W. (2007). *Physics* (7th ed.). New Jersey: John Wiley & Sons, Inc.

Serway, R. A., & Beichner, R. J. (2000). *Physics for Scientist and Engineers* (5th ed.). New York: Saunders College Publishing.

Walker, J. (2008). *Fundamentals of physics* (8th ed.). New Jersey: John Wiley & Sons, Inc.

LESSON SIX

TOPIC: Resistors Connected in Parallel.

DURATION: 120 minutes

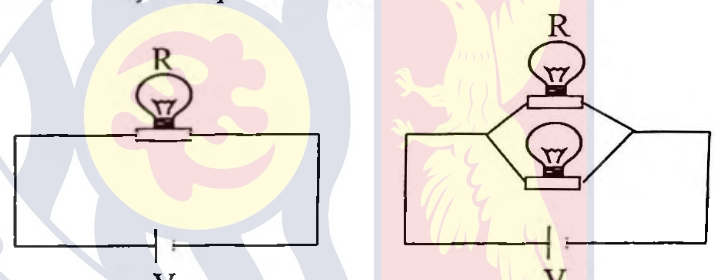
RELEVANT PREVIOUS KNOWLEDGE: Students are familiar with series connection of resistors in a circuit.

SPECIFIC OBJECTIVES: By the end of the lesson, the student should be able to:

1. describe the brightness of bulbs connected in parallel in a circuit.
2. measure, and identify through experimentation, that the current in the main circuit is the sum of currents in the sub-circuits.
3. measure, and identify through experimentation, that the voltage across each of the resistors in parallel is equal to that of the source voltage.
4. deduce the general relation for resistors connected in parallel in a circuit.

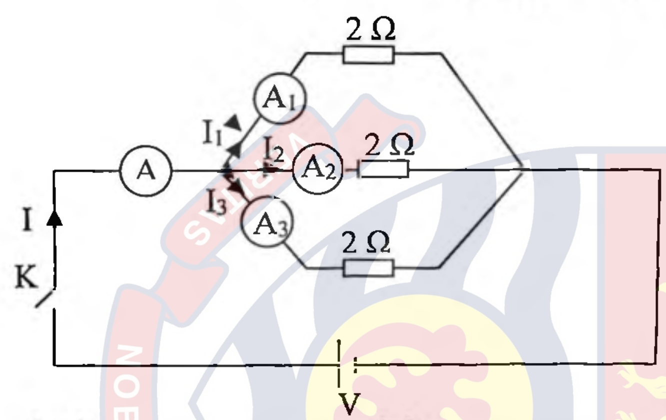
TEACHING/LEARNING MATERIALS: Computer with Circuit Construction Kit (CCK) software installed, dry cells or power supply, three bulbs, key, ammeters, three 2 Ω resistors, a 3 Ω resistor, 4 Ω resistor and connecting wires.

ADVANCED PREPARATION: Teacher prepares the laboratory and gets all teaching and learning materials ready for the lesson and also tries them out to ensure that they can help achieve the desired results.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Exploration Stage (75 minutes)	1. Teacher gives activity sheets to students and guides students in groups to perform the activities on the sheet using the CCK and also repeat the activity using real circuit components. <u>INSTRUCTIONAL SHEET TEN</u> a. Using your materials, set up Circuit 1.  Circuit 1 Circuit 2 b. Predict what you expect about the brightness of bulb R if one more identical bulb is added to the circuit (as shown in Circuit 2). Explain your response. c. Discuss your predictions and reasons among yourselves.	1. Students in their groups read through the instructions on the activity sheet carefully and follow it to perform the activities using the CCK and also with real circuit components.	

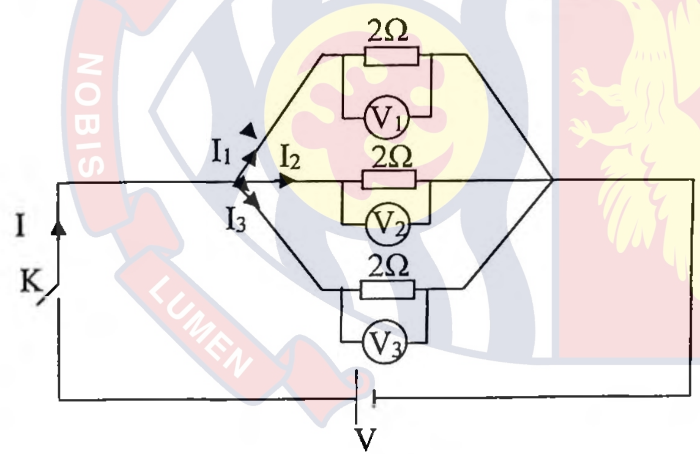
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	d. Using your materials, set up Circuit 2. e. What did you observe in the brightness of the bulbs in Circuit 2? f. Had your observation confirmed your prediction? Yes/No. g. Which circuit had the brightest bulb(s), Circuit 1 or Circuit 2? h. Why is this so? i. What conclusion can you give for this observation? K What would happen should you unscrew one bulb in Circuit 2? l Try this out. m Did you observation match up with your prediction? n What will happen to the brightness of the bulbs if one more identical bulb is added to those in Circuit 2? o Try this out. What did you observe?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	p. Suppose you had a string of Christmas tree lights connected like in Circuit 2, what would happen to the bulbs when one of the bulbs is unscrewed off? q. What is the name given to a circuit that contains bulbs arranged like in Circuit 2?		
	2. Teacher gives students instructional sheet eleven and asks them to perform the activities using the CCK and also repeat it using real circuit components.	2. Students read through the instructions on the sheet and perform the activities first using the CCK and also with real circuit components.	

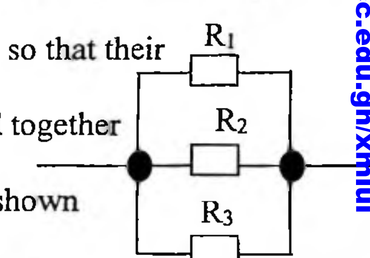
<table>
<tr><th>STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)</th><th>TEACHER ACTIVITY</th><th>STUDENT ACTIVITY</th><th>KEY IDEAS</th></tr>
<tr><td></td><td>
<u>INSTRUCTIONAL SHEET ELEVEN</u>


a. In the circuit diagram, will the reading on ammeters A_1, A_2, A_3 and A_4 be the same or different? Explain your response.
b. Discuss your predictions and reasons among yourselves.
c. Using the materials, set up the circuit as shown in the circuit diagram shown. Explain your response.
</td><td></td><td></td></tr>
</table>

	d. Close the key and note down the value of the current passing through each ammeter in turns. $A = \ldots\ldots A$ $A_1 = \ldots\ldots A$ $A_2 = \ldots\ldots A$ $A_3 = \ldots\ldots\ldots A$ e. Are there any differences between your response (in Step1) and experimental results (in Step 4)? Yes/No. f. Replace two of the 2 Ω resistors with the 3 Ω and 4 Ω resistors respectively and note down the ammeter readings in turns. $A = \ldots\ldots A$ $A_1 = \ldots\ldots A$ $A_2 = \ldots\ldots A$ $A_3 = \ldots\ldots\ldots A$ g. Are there any differences between the results (in step 4) and the results (in step 6)? Yes/No. h. What conclusions can you draw about the experiment?		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	3. Teacher gives students instructional sheet twelve and asks them to perform the activities using the CCK and also repeat it using real circuit components. INSTRUCTIONAL SHEET TWELVE  a. In the circuit diagram, will the reading on voltmeter V_1, V_2, and V_3 be the same or different? Explain your response.	3. Students in their groups read through the instructions on the sheet and perform the activities first using the CCK and also with real circuit components.	.

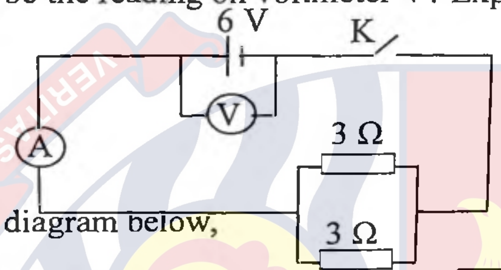
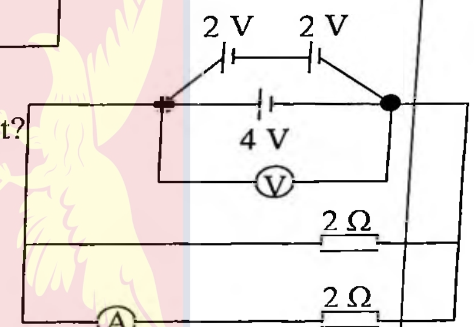
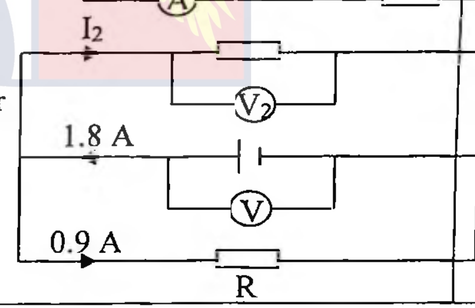
STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	b. Discuss your predictions and reasons among yourselves. c. Using the materials, set up the circuit as shown in the circuit diagram. d. Close the key and note down the voltage across each of the resistors in turns. V_1 = ……V V_2 = ……V V_3 = ……V e. Are there any differences between your response (in Step 1) and experimental results (in Step 4)? Yes/No f. Replace two of the 2 Ω resistors with the 3 Ω and 4 Ω resistors respectively and note down the voltmeter readings in turns. V_1 = ……V V_2 = ……V V_3 = ……V g. Are there any differences between the results in Step 4 and the results in Step 6? Yes/No.		

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	h. What conclusions can you draw about the experiment?		
Explanation Stage 30 minutes	Teacher summaries all that has been done in the three activities to students.	Students listen and ask questions where necessary	1. Similar bulbs connected in parallel to a cell produce the same brightness but dissimilar bulbs produce varying brightness depending on their resistances. 2. When one of the bulbs is disconnected in a sub-circuit, others in the other sub-circuits continue to glow. 3. The arrangement whereby two or more resistors (or bulbs) are connected side by side and so that their corresponding ends are joined together at their respective points (as shown below) is called parallel connection of resistors. 

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
			4. The current in the main circuit is the algebraic sum of all the currents in the sub-circuits. $I = I_1 + I_2 + I_3 + \ldots . I_n$ 5. The current in the main circuit is shared equally among similar resistors in the sub-circuits and proportionally among unequal resistors. 6. The voltage across each of the resistors connected in parallel in a circuit is equal to that of the source voltage. 7. For any parallel connection of resistor in a circuit, the voltage across each of the resistors is the same while the current passing through each of the resistors is different. From Ohm's law $V = IR$, i.e., $I = \frac{V}{R}$

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
			Hence, the currents across each of the resistors are given by $I_1 = \frac{V}{R_1}, \; I_2 = \frac{V}{R_2} \; and \; I_3 = \frac{V}{R_3}$ But the total current in the circuit is given by $I = I_1 + I_2 + I_3$ ∴ Substituting equation 2 and 3 into 4, we get $\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$ $\therefore \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ Generally, if there are two or more resistors connected in parallel in a circuit, the effective resistance R can be given as

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
Expansion Stage (25 minutes)	Teacher asks students do the following exercises: 1. In the circuit diagram, the key (K) is open. a. What is the effective resistance in the circuit?	Students do the exercises individually and compare their answers with group members.	$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+...+\frac{1}{R_N}$ 8. Currents in the sub-circuits are inversely proportional to the resistance in their respective circuits in a parallel connection of resistors in a circuit.

STAGE/STEP/CONTENT ITEM (ESTIMATED TIME)	TEACHER ACTIVITY	STUDENT ACTIVITY	KEY IDEAS
	b. What will be the reading on ammeter A? Explain your answer. c. What will be the reading on voltmeter V? Explain your answer.  2. In the circuit diagram below, a. What is the effective resistance in the circuit? b. What is the reading on the voltmeter? c. What is the reading on the ammeter?  3. In the circuit diagram above, a. What will be the reading of voltmeter V_1 if V_2 reads 4V? b. What is the value of the current I_2? 		

REMARKS:

REFERENCES:

Cutnell, J. D., & Johnson, K. W. (2007). *Physics* (7th ed.). New Jersey: John Wiley & Sons, Inc.

Serway, R. A., & Beichner, R. J. (2000). *Physics for Scientist and Engineers* (5th ed.). New York: Saunders College Publishing.

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APPENDIX J

DESCRIPTION OF MCNEMAR CHI-SQUARE AND CHI-SQUARE DISTRIBUTION TABLE

To determine the degree of change in students' conceptions from the pretest to the posttest for each question in ECCT for the HACL and FCL groups, the McNemar Chi-Square test for significance of change was used. To do this, a fourfold table of frequencies was set up to represent the pretest and posttest sets of responses from the same student. The features of the table are illustrated in Figure 6, in which positive (+) and negative (–) signs are used to signify the different responses given by students.

		After -	After +
Before	+	A	B
	-	C	D

Figure 6: Fourfold table used in testing significance of change

The '+' sign means there is no alternative conception before or after intervention and the '–' sign means presence of alternative conception before or after intervention.

A student is tailed in cell 'A' if there is a change in conception from '+' to '–' and tailed in cell 'D' if there is a change from '–' to '+'. This means presence of change in conception before and after intervention occurs only in cells 'A' and 'D'. However, if there is no change in conception, the student is tailed in cell 'B' if the response is '+' both before and after intervention, and tailed in cell 'C' if the response is '–' both before and after intervention. From these, the McNemar formula is given by

$$\chi^2 = \frac{(|A-D|-1)^2}{A+D} \quad \text{with } df = 1$$

This formula is used to calculate the degree of change in students' alternative conception from pretest to posttest. That is, if the observed critical value for χ^2 is equal to or greater than 3.84 at $\alpha = .05$ for a particular significance level of $df = 1$, the implication is that a 'significant' effect was demonstrated in the pretest and posttest responses (Glantz, 2005). This means that if the $\chi^2 \geq 3.84$, then the p-value will be less than *.05* and the null hypothesis for equal proportions between groups will be rejected.

CHI-SQURE DISTRIBUTION TABLE

df	Probability of the Chi-Square [P (χ^2)]								
	0.995	0.975	0.9	0.5	0.1	0.05	0.05	0.01	0.005
1	0.000	0.000	0.016	0.455	2.706	3.841	5.024	6.635	7.879
2	0.010	0.051	0.211	1.386	4.605	5.991	7.378	9.210	10.597
3	0.072	0.216	0.584	2.366	6.251	7.815	9.348	11.345	12.838
4	0.207	0.484	1.064	3.357	7.779	9.488	11.143	13.277	14.860
5	0.412	0.831	1.610	4.351	0.236	11.070	12.832	15.086	16.750
6	0.676	1.237	2.402	5.348	10.645	12.592	14.449	16.812	18.548
7	0.989	1.690	2.833	6.346	12.017	14.067	16.013	18.475	20.278
8	1.344	2.180	3.490	7.344	13.362	15.507	17.535	20.090	21.955
9	1.735	2.700	4.168	8.343	14.684	16.919	19.023	21.666	23.589
10	2.156	3.247	4.865	9.342	15.987	18.307	20.483	23.209	25.188

APPENDIX K

SPSS OUTPUT FOR ASSUMPTION TESTING OF PRETESTS

Normality

One-Sample Kolmogorov-Smirnov Test

		Galtpretest	CECATPretest
N		110	110
Normal Parameters[a]	Mean	5.38	12.85
	Std. Deviation	1.981	3.115
MostExtreme Differences	Absolute	.211	.126
	Positive	.121	.126
	Negative	-.211	-.071
Kolmogorov-Smirnov Z		2.214	1.324
Asymp. Sig. (2-tailed)		.000	.060

a. Test distribution is Normal.

Multivariate Outliers and Multivariate Normality

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.46	1.53	1.50	.015	110
Std. Predicted Value	-2.615	2.200	.000	1.000	110
Standard Error of Predicted Value	.048	.135	.065	.020	110
Adjusted Predicted Value	1.42	1.56	1.50	.018	110
Residual	-.532	.539	.000	.502	110
Std. Residual	-1.056	1.068	.000	.995	110
Stud. Residual	-1.085	1.108	-.001	1.005	110
Deleted Residual	-.563	.580	-.001	.511	110
Stud. Deleted Residual	-1.086	1.109	-.001	1.005	110
Mahal. Distance	.002	6.838	.991	1.381	110
Cook's Distance	.005	.048	.009	.007	110
Centered Leverage Value	.000	.063	.009	.013	110

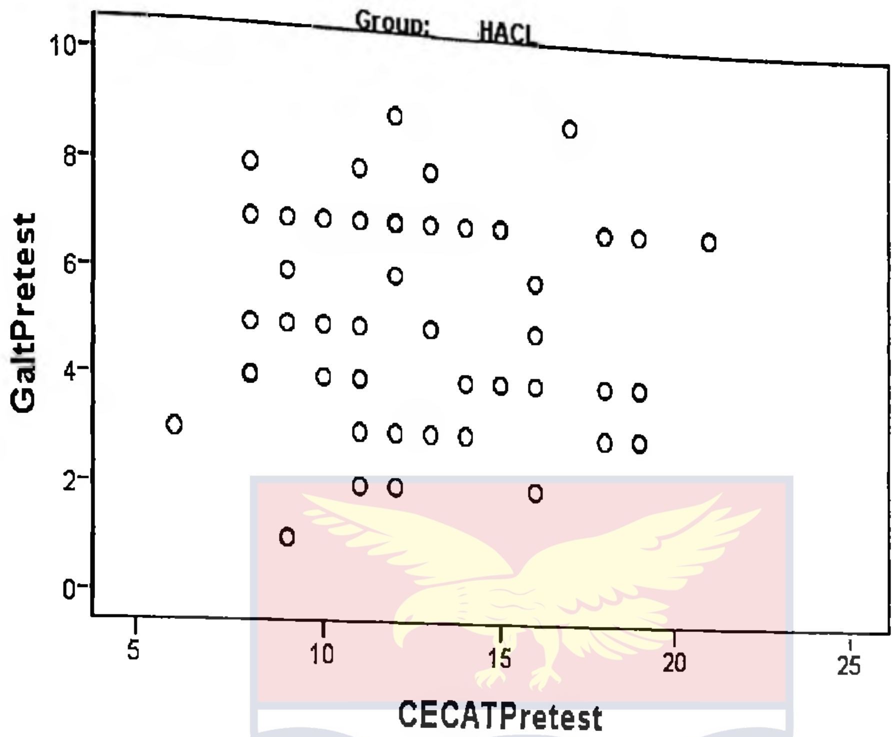
a. Dependent Variable: Group

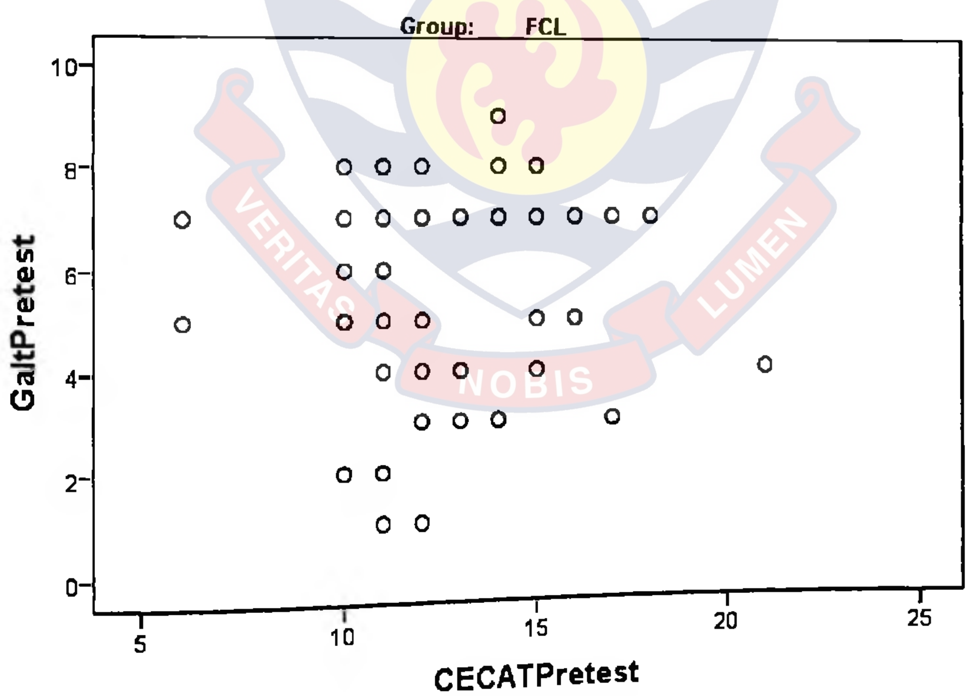
Extreme Values

			Case Number	Group	Value
Mahalanobis Distance	Highest	1	49	HACL	6.83763
		2	82	FCL	6.83763
		3	33	HACL	4.84209
		4	63	FCL	4.84209
		5	108	FCL	4.84209
	Lowest	1	95	FCL	.00218
		2	90	FCL	.00218
		3	79	FCL	.00218
		4	76	FCL	.00218
		5	68	FCL	.00218[a]

a. Only a partial list of cases with the value .00218 are shown in the table of lower extremes.

Linearity and Multicollinearity





Homogeneity of Variance-Covariance Matrices

Descriptive Statistics

	Group	Mean	Std. Deviation	N
GaltPretest	HACL	5.35	1.974	55
	FCL	5.42	2.006	55
	Total	5.38	1.981	110
CECATPretest	HACL	12.95	3.498	55
	FCL	12.76	2.708	55
	Total	12.85	3.115	110

Box's Test of Equality of Covariance Matrices[a]

Box's M	3.527
F	1.152
df1	3
df2	2.100E6
Sig.	.327

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept + Group

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
GaltPretest	.012	1	108	.915
CECATPretest	4.963	1	108	.028

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Intercept	Pillai's Trace	.959	1.257E3[a]	2.000	107.000	.000	.959	2513.264	1.000
	Wilks' Lambda	.041	1.257E3[a]	2.000	107.000	.000	.959	2513.264	1.000
	Hotelling's Trace	23.488	1.257E3[a]	2.000	107.000	.000	.959	2513.264	1.000
	Roy's Largest Root	23.488	1.257E3[a]	2.000	107.000	.000	.959	2513.264	1.000
Group	Pillai's Trace	.001	.068[a]	2.000	107.000	.935	.001	.135	.060
	Wilks' Lambda	.999	.068[a]	2.000	107.000	.935	.001	.135	.060
	Hotelling's Trace	.001	.068[a]	2.000	107.000	.935	.001	.135	.060
	Roy's Largest Root	.001	.068[a]	2.000	107.000	.935	.001	.135	.060

a. Exact statistic

b. Computed using alpha = .05

c. Design: Intercept + Group

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	GaltPretest	.145[a]	1	.145	.037	.848	.000	.037	.054
	CECATPretest	.909[c]	1	.909	.093	.761	.001	.093	.061
Intercept	GaltPretest	3186.036	1	3186.036	804.295	.000	.882	804.295	1.000
	CECATPretest	18176.327	1	18176.327	1.858E3	.000	.945	1857.599	1.000
Group	GaltPretest	.145	1	.145	.037	.848	.000	.037	.054
	CECATPretest	.909	1	.909	.093	.761	.001	.093	.061
Error	GaltPretest	427.818	108	3.961					
	CECATPretest	1056.764	108	9.785					
Total	GaltPretest	3614.000	110						
	CECATPretest	19234.000	110						
Corrected Total	GaltPretest	427.964	109						
	CECATPretest	1057.673	109						

a. R Squared = .000 (Adjusted R Squared = -.009)

b. Computed using alpha = .05

APPENDIX L

GROUP COHESIVENESS QUESTIONNAIRE AND SPSS OUTPUT DATA

UNIVERSITY OF CAPE COAST

DEPARTMENT OF SCIENCE AND MATHEMATICS EDUCATION

This questionnaire seeks to find out your views about group work. Please tick the appropriate box provided. Your responses will be treated as confidential and will be used only for research purposes and so respond to the items as truthfully as possible. Where SD = Strongly Disagree, D = Disagree, U = Undecided, A = Agree, SA = Strongly Agree

Item	SD	D	U	A	SA
1. Working in a group help me learn specific skills, facts, algorithms and concepts better.					
2. Members of my group work for the betterment of the group.					
3. The members in my group put effort into achieving group goals together.					
4. I like making the effort to abide by the rules set by the group.					
5. The group works toward an agreement before an action is taken.					
6. I am happy about the success of the group.					
7. I make positive contributions toward the success of the group.					
8. The members prefer working with the group rather than working independently.					
9. Working in a group improves my relationship with my classmates.					
10 Working in a group helps me get the work completed on time					

SPSS OUTPUT DATA OF GROUP COHESIVENESS QUESTIONNAIRE

Descriptive Statistics for the HACL group

	N	Minimum	Maximum	Mean	Std. Deviation
Working in a group help me learn specific skills, facts, algorithms and concepts better	54	2	5	4.13	.825
Members of my group work for the betterment of the group	54	1	5	4.02	1.141
The members in my group put effort into achieving group goals together.	54	2	5	4.26	.955
I like making the effort to abide by the rules set by the group.	54	1	5	4.17	.906
The group works toward an agreement before an action is taken	54	1	5	3.83	1.095
I am happy about the success of the group.	54	2	5	4.19	.779
I make positive contributions toward the success of the group.	54	2	5	4.48	.693
The members prefer working with the group rather than working independently.	54	1	5	3.65	1.135
Working in a group improves my relationship with my classmates.	54	2	5	4.26	.935
Working in a group helps me get the work completed on time	54	1	5	3.98	1.221
Valid N (listwise)	54				

Descriptive Statistics for the FCL group

	N	Minimum	Maximum	Mean	Std. Deviation
Working in a group help me learn specific skills, facts, algorithms and concepts better	52	2	5	4.00	1.029
Members of my group work for the betterment of the group	52	3	5	4.38	.565
The members in my group put effort into achieving group goals together.	52	2	5	4.52	.671
I like making the effort to abide by the rules set by the group.	52	2	5	4.12	.808
The group works toward an agreement before an action is taken	52	2	5	4.38	.796
I am happy about the success of the group.	52	3	5	4.21	.637
I make positive contributions toward the success of the group.	52	2	5	4.23	.783
The members prefer working with the group rather than working independently.	52	2	5	4.27	.744
Working in a group improves my relationship with my classmates.	52	2	5	4.25	.789
Working in a group helps me get the work completed on time	52	1	5	3.92	1.169
Valid N (listwise)	52				

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
FCL GRAND MEAN	52	4	5	4.23	.324
HACL GRAND MEAN	54	3	5	4.09	.525
Valid N (listwise)	52				

APPENDIX M

SPSS OUTPUT FOR ASSUMPTION TESTING OF POSTTESTS

Normality

One-Sample Kolmogorov-Smirnov Test

		GALTPOST	CECATPOST
N		106	107
Normal Parameters[a]	Mean	6.16	18.92
	Std. Deviation	2.010	3.737
MostExtreme Differences	Absolute	.134	.092
	Positive	.083	.092
	Negative	-.134	-.076
Kolmogorov-Smirnov Z		1.376	.953
Asymp. Sig. (2-tailed)		.045	.324

a. Test distribution is Normal.

Multivariate Outliers and Multivariate Normality

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.92	2.06	1.49	.236	106
Std. Predicted Value	-2.422	2.390	.000	1.000	106
Standard Error of Predicted Value	.044	.144	.072	.021	106
Adjusted Predicted Value	.91	2.06	1.49	.235	106
Residual	-.746	.830	.000	.443	106
Std. Residual	-1.666	1.854	.000	.990	106
Stud. Residual	-1.701	1.879	.000	1.001	106
Deleted Residual	-.777	.853	.000	.453	106
Stud. Deleted Residual	-1.717	1.903	.000	1.005	106
Mahal. Distance	.007	9.924	1.981	1.837	106
Cook's Distance	.000	.041	.007	.007	106
Centered Leverage Value	.000	.095	.019	.017	106

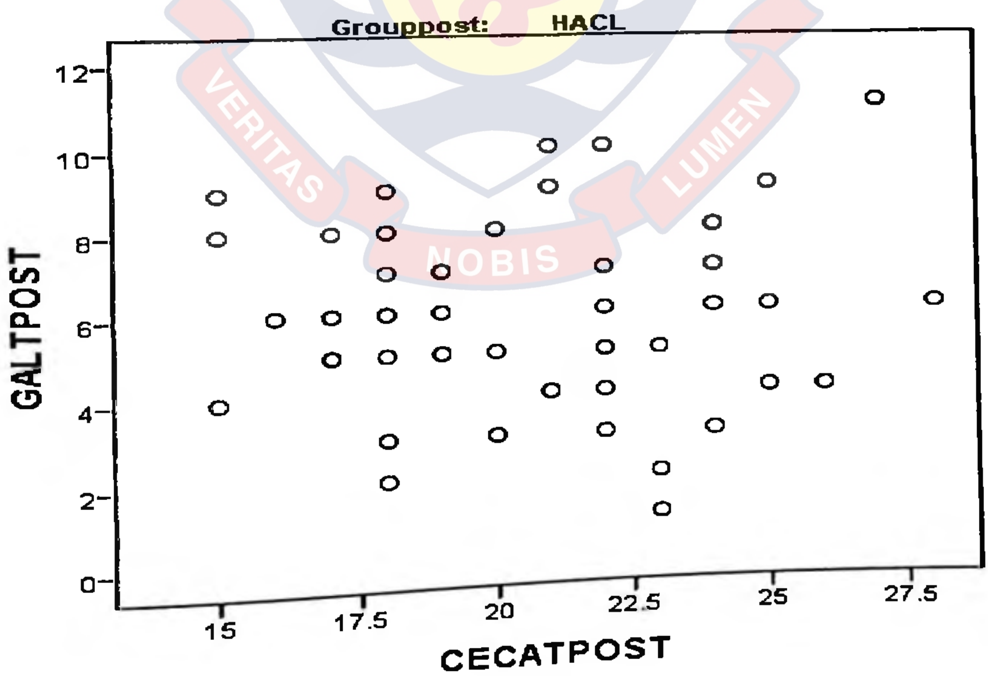
a. Dependent Variable: Grouppost

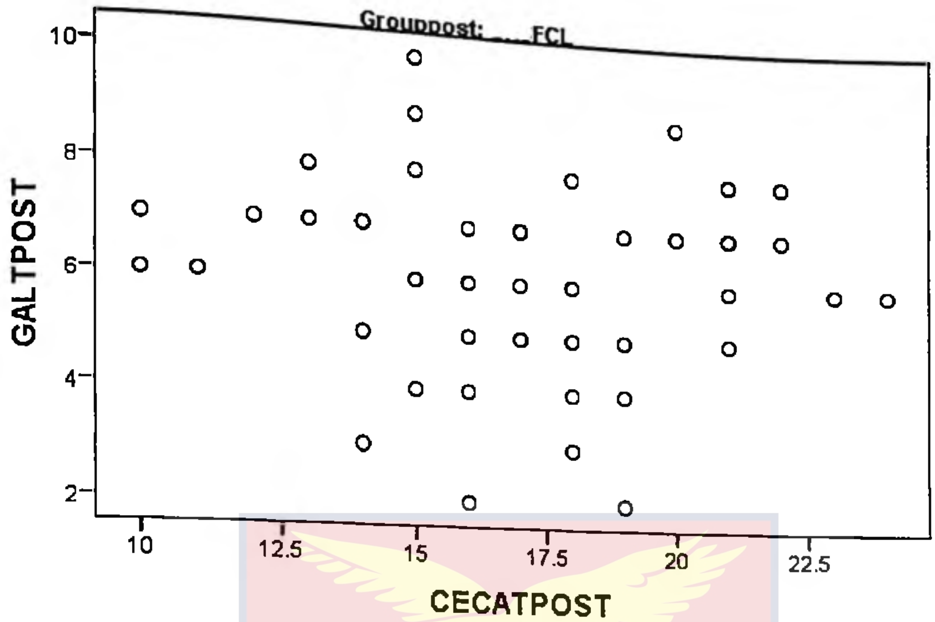
Extreme Values

			Case Number	Grouppost	Value
Mahalanobis Distance	Highest	1	42	HACL	9.92393
		2	52	HACL	8.07349
		3	100	FCL	5.94378
		4	2	HACL	5.88699
		5	14	HACL	5.70572
	Lowest	1	54	HACL	.00695
		2	105	FCL	.06520
		3	53	HACL	.06520
		4	48	HACL	.06520
		5	61	FCL	.17447[a]

a. Only a partial list of cases with the value .17447 are shown in the table of lower extremes.

Linearity and Multicollinearity





Homogeneity of Variance-Covariance Matrices

Descriptive Statistics

	Grouppost	Mean	Std. Deviation	N
GALTPOST	HACL	6.19	2.232	54
	FCL	6.13	1.772	52
	Total	6.16	2.010	106
CECATPOST	HACL	20.65	3.257	54
	FCL	17.13	3.401	52
	Total	18.92	3.754	106

Box's Test of Equality of Covariance Matrices[a]

Box's M	2.976
F	.971
df1	3
df2	2.042E6
Sig.	.405

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept + Grouppost

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
GALTPOST	2.915	1	104	.091
CECATPOST	.000	1	104	.994

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Grouppost

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.976	2.091E3[a]	2.000	103.000	.000	.976
	Wilks' Lambda	.024	2.091E3[a]	2.000	103.000	.000	.976
	Hotelling's Trace	40.604	2.091E3[a]	2.000	103.000	.000	.976
	Roy's Largest Root	40.604	2.091E3[a]	2.000	103.000	.000	.976
Grouppost	Pillai's Trace	.221	14.626[a]	2.000	103.000	.000	.221
	Wilks' Lambda	.779	14.626[a]	2.000	103.000	.000	.221
	Hotelling's Trace	.284	14.626[a]	2.000	103.000	.000	.221
	Roy's Largest Root	.284	14.626[a]	2.000	103.000	.000	.221

a. Exact statistic

b. Design: Intercept + Grouppost

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	GALTPOST	.068[a]	1	.068	.017	.898	.000
	CECATPOST	327.024[b]	1	327.024	29.513	.000	.221
Intercept	GALTPOST	4020.672	1	4020.672	985.724	.000	.905
	CECATPOST	37816.269	1	37816.269	3.413E3	.000	.970
Grouppost	GALTPOST	.068	1	.068	.017	.898	.000
	CECATPOST	327.024	1	327.024	29.513	.000	.221
Error	GALTPOST	424.206	104	4.079			
	CECATPOST	1152.373	104	11.081			
Total	GALTPOST	4447.000	106				
	CECATPOST	39442.000	106				
Corrected Total	GALTPOST	424.274	105				
	CECATPOST	1479.396	105				

a. R Squared = .000 (Adjusted R Squared = -.009)

b. R Squared = .221 (Adjusted R Squared = .214)

APPENDIX N

CALCULATION OF THE EFFECT SIZE STATISTICS FOR DEPENDENT SAMPLES T-TEST OF PRETEST AND POSTTEST IN SCIENTIFIC REASONING AND CONCEPTUAL UNDERSTANDING FOR HACL AND FCL GROUPS

$$d = \frac{t}{\sqrt{N}}$$

Where d = Effect size

t = Value of t in the output under the dependent samples t-test.

N = Number of students

Effect size statistics of scientific reasoning for HACL group

$$d = \frac{2.092}{\sqrt{54}} = .28$$

Effect size statistics of scientific reasoning for FCL group

$$d = \frac{2.040}{\sqrt{52}} = .28$$

Effect size statistics of conceptual understanding for HACL group

$$d = \frac{12.780}{\sqrt{54}} = 1.78$$

Effect size statistics of conceptual understanding for FCL group

$$d = \frac{7.195}{\sqrt{53}} = .99$$

APPENDIX O

EXTENDED VERSION OF TABLE 18

	HACL group [N = 51]							FCL group [N = 49]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
1	1	21	3	26	29(56.9)	4(7.8)	21.333*	2	24	4	19	23(46.9)	6(12.2)	12.190*
2	6	20	5	20	25(49.0)	11(21.6)	6.500*	2	27	3	17	20(40.8)	5(10.2)	10.316*
3	1	3	19	28	47(92.2)	20(39.2)	23.310*	2	3	25	19	44(89.8)	27(55.1)	12.190*
4	1	15	15	20	35(68.6)	16(31.4)	15.429*	7	14	13	15	28(57.1)	20(40.8)	2.227
5	1	4	34	12	46(90.2)	35(68.6)	7.692*	0	1	37	11	48(98.0)	37(75.5)	9.090*
6	0	7	9	35	44(86.3)	9(18.4)	33.029*	5	2	39	3	42(85.7)	44(89.8)	1.125
7	0	4	10	37	47(92.2)	10(20.4)	35.027*	5	1	40	3	43(87.8)	45(91.8)	1.125
8	0	13	6	32	38(74.5)	6(11.8)	30.031*	3	8	11	27	38(77.6)	14(28.6)	17.633*
9	0	6	11	34	45(88.2)	11(21.6)	32.029*	6	4	17	22	39(79.6)	23(46.9)	8.036*

Figures in parenthesis are percentages

*Significant at $\chi^2 \geq 3.84$

APPENDIX P

EXTENDED VERSION OF TABLE 47

	HD Students in HACL group [N = 21]							HD students in FCL group [N = 23]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
1	1	11	0	9	9(42.9)	1(4.8)	4.900*	0	15	1	7	8(34.8)	1(4.3)	5.143*
2	1	12	0	8	8(38.1)	1(4.8)	4.000*	0	15	0	8	8(34.8)	0(.0)	6.125*
3	0	1	4	16	20(95.2)	4(19.0)	14.063*	1	3	6	13	19(82.6)	7(30.4)	8.643*
4	0	8	2	11	13(61.9)	2(9.5)	9.091*	3	9	1	10	11(47.8)	4(17.4)	2.769
5	0	3	9	9	18(85.7)	9(42.9)	7.111*	0	0	15	8	23(100.0)	15(65.2)	6.125*
6	0	3	2	16	18(85.7)	2(9.5)	14.063*	3	1	16	3	19(82.6)	19(82.6)	.000
7	0	1	0	20	20(95.2)	0(.0)	18.050*	2	1	18	2	20(87.0)	20(87.0)	.000
8	0	8	2	11	13(61.9)	2(9.5)	9.091*	0	4	3	16	19(82.6)	3(13.0)	14.063*
9	0	5	1	15	16(76.2)	1(4.8)	13.067*	4	2	2	15	17(73.9)	6(26.1)	5.263*

Figures in parenthesis are percentages

*Significant at $\chi^2 \geq 3.84$

APPENDIX Q

EXTENDED VERSION OF TABLE 48

	EI Students in HACL group [N = 30]							EI Students in FCL group [N = 26]						
Question	A	B	C	D	Pretest	Posttest	χ^2	A	B	C	D	Pretest	Posttest	χ^2
1	0	10	3	17	20(66.7)	3(10.0)	15.059*	2	9	3	12	15(57.7)	5(19.2)	5.786*
2	5	8	5	12	17(56.7)	10(33.3)	2.118	2	12	3	9	12(46.2)	5(19.2)	3.273
3	1	2	15	12	27(90.0)	16(39.2)	7.692*	1	0	19	6	25(96.2)	20(55.1)	2.286
4	1	7	13	9	22(73.3)	14(46.7)	4.900*	4	5	12	5	17(65.4)	16(61.5)	.000
5	1	1	25	3	28(93.3)	26(86.7)	.250	0	1	22	3	25(96.2)	22(84.6)	1.333
6	0	4	7	19	26(86.7)	7(23.3)	17.053*	2	1	23	0	23(88.5)	25(96.2)	.500
7	0	3	10	17	27(90.0)	10(33.3)	15.059*	3	0	22	1	23(88.5)	25(96.2)	.250
8	0	5	4	21	25(83.3)	4(13.3)	19.048*	3	4	8	11	19(73.1)	11(42.3)	3.500
9	0	1	10	19	29(96.7)	10(33.3)	17.053*	2	2	15	7	22(84.6)	17(65.4)	1.778

Figures in parenthesis are percentages

*Significant at $\chi^2 \geq 3.84$

APPENDIX R

SPSS OUTPUT FOR ASSUMPTION TESTING OF MANCOVA

Descriptive Statistics

	Instructional Method	moderator1	Mean	Std. Deviation	N
SR	HACL	HD	8.38	1.071	21
		EI	6.48	.939	33
		Total	7.22	1.355	54
	FCL	HD	7.59	.854	22
		EI	5.38	1.115	29
		Total	6.33	1.492	51
	Total	HD	7.98	1.035	43
		EI	5.97	1.159	62
		Total	6.79	1.485	105
CU	HACL	HD	23.76	1.972	21
		EI	18.67	2.175	33
		Total	20.65	3.257	54
	FCL	HD	20.23	1.771	22
		EI	14.76	2.166	29
		Total	17.12	3.380	51
	Total	HD	21.95	2.572	43
		EI	16.84	2.915	62
		Total	18.93	3.747	105

Box's Test of Equality of Covariance Matrices[a]

Box's M	13.356
F	1.429
df1	9
df2	7.263E4
Sig.	.169

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

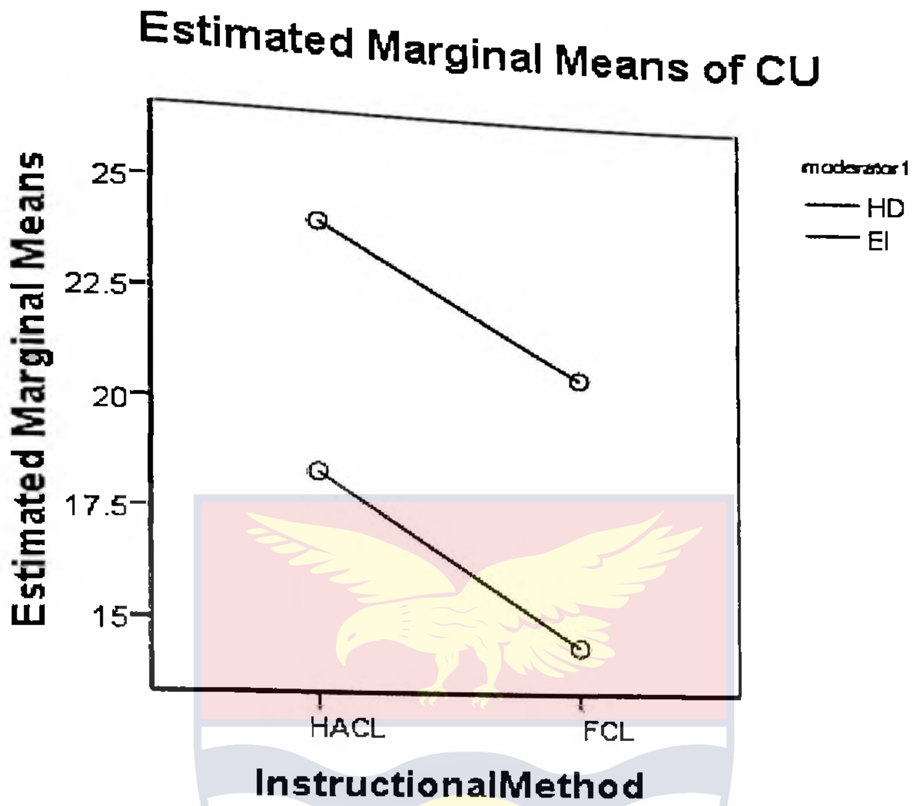
a. Design: Intercept + PreSR + PreCU + InstructionalMethod + moderator1 + InstructionalMethod * moderator1

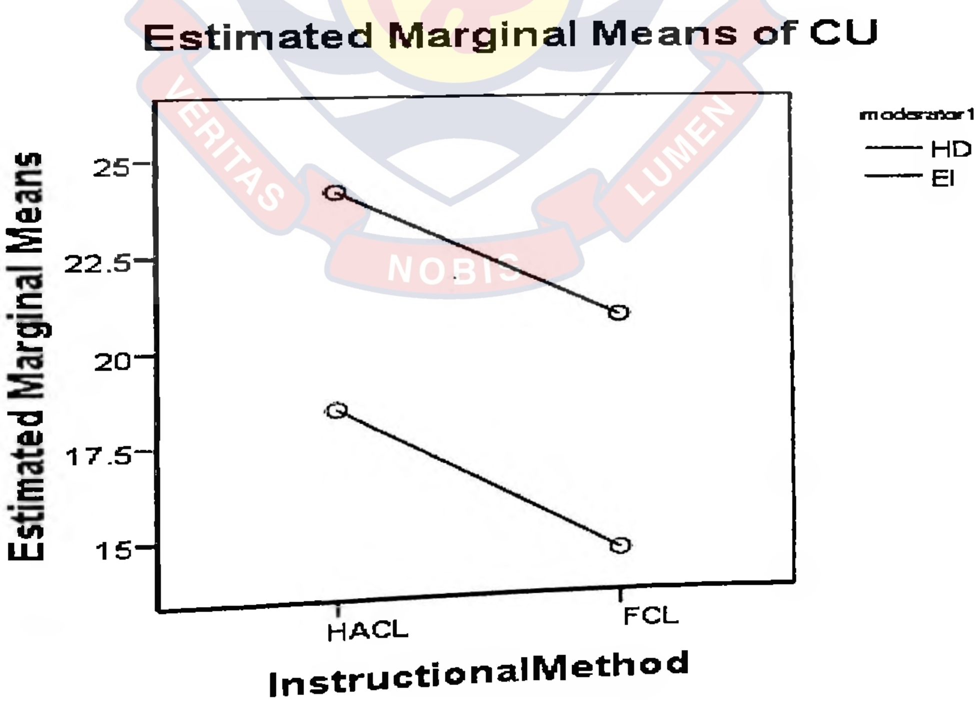
Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
SR	.807	3	101	.493
CU	.089	3	101	.966

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + PreSR + PreCU + InstructionalMethod + moderator1 + InstructionalMethod * moderator1


Estimated Marginal Means of CU
Estimated Marginal Means
25
22.5
20
17.5
15
HACL
FCL
InstructionalMethod
moderator1
HD
EI


Estimated Marginal Means of CU
Estimated Marginal Means
25
22.5
20
17.5
15
HACL
FCL
InstructionalMethod
moderator1
HD
EI

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.768	1.624E2[a]	2.000	98.000	.000	.768
	Wilks' Lambda	.232	1.624E2[a]	2.000	98.000	.000	.768
	Hotelling's Trace	3.313	1.624E2[a]	2.000	98.000	.000	.768
	Roy's Largest Root	3.313	1.624E2[a]	2.000	98.000	.000	.768
PreSR	Pillai's Trace	.038	1.956[a]	2.000	98.000	.147	.038
	Wilks' Lambda	.962	1.956[a]	2.000	98.000	.147	.038
	Hotelling's Trace	.040	1.956[a]	2.000	98.000	.147	.038
	Roy's Largest Root	.040	1.956[a]	2.000	98.000	.147	.038
PreCU	Pillai's Trace	.023	1.152[a]	2.000	98.000	.320	.023
	Wilks' Lambda	.977	1.152[a]	2.000	98.000	.320	.023
	Hotelling's Trace	.024	1.152[a]	2.000	98.000	.320	.023
	Roy's Largest Root	.024	1.152[a]	2.000	98.000	.320	.023
InstructionalMethod	Pillai's Trace	.538	57.024[a]	2.000	98.000	.000	.538
	Wilks' Lambda	.462	57.024[a]	2.000	98.000	.000	.538
	Hotelling's Trace	1.164	57.024[a]	2.000	98.000	.000	.538
	Roy's Largest Root	1.164	57.024[a]	2.000	98.000	.000	.538

moderator1	Pillai's Trace	.465	42.655[a]	2.000	98.000	.000	.465
	Wilks' Lambda	.535	42.655[a]	2.000	98.000	.000	.465
	Hoteiling's Trace	.871	42.655[a]	2.000	98.000	.000	.465
	Roy's Largest Root	.871	42.655[a]	2.000	98.000	.000	.465
InstructionalMethod * moderator1	Pillai's Trace	.009	.464[a]	2.000	98.000	.630	.009
	Wilks' Lambda	.991	.464[a]	2.000	98.000	.630	.009
	Hotelling's Trace	.009	.464[a]	2.000	98.000	.630	.009
	Roy's Largest Root	.009	.464[a]	2.000	98.000	.630	.009

a. Exact statistic

b. Design: Intercept + PreSR + PreCU + InstructionalMethod + moderator1 + InstructionalMethod * moderator1

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	SR	130.001[a]	5	26.000	25.898	.000	.567
	CU	1052.839[b]	5	210.568	51.132	.000	.721
Intercept	SR	98.025	1	98.025	97.641	.000	.497
	CU	827.358	1	827.358	200.906	.000	.670
PreSR	SR	1.154	1	1.154	1.149	.286	.011
	CU	12.872	1	12.872	3.126	.080	.031
PreCU	SR	.905	1	.905	.902	.345	.009
	CU	6.733	1	6.733	1.635	.204	.016
InstructionalMethod	SR	23.492	1	23.492	23.400	.000	.191
	CU	339.564	1	339.564	82.456	.000	.454
moderator1	SR	22.180	1	22.180	22.093	.000	.182
	CU	233.146	1	233.146	56.615	.000	.364
InstructionalMethod * moderator1	SR	.377	1	.377	.376	.541	.004
	CU	1.948	1	1.948	.473	.493	.005

Error	SR	99.390	99	1.004			
	CU	407.695	99	4.118			
Total	SR	5071.000	105				
	CU	39100.000	105				
Corrected Total	SR	229.390	104				
	CU	1460.533	104				

a. R Squared = .567 (Adjusted R Squared = .545)

b. R Squared = .721 (Adjusted R Squared = .707)