

Measuring the Impact of Electric Circuits KitBook on Elementary School Children's Understanding of Simple Electric Circuits

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Abstract

This study examined the impact of Electric Circuits Kitbook on 4th grade elementary school children's understanding of simple electric circuits. Sample consists of 100 elementary school children randomly selected from two school districts and six classrooms. Three classrooms were randomly assigned as the treatment group and the other three were assigned as the control group. The Electric Circuits Concept Inventory Test was administered to both groups after one week of science instruction. Findings suggest that the treatment group students performed significantly better than the control group students.

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Introduction

The concept of electricity and magnetism is central to elementary school science curriculum. The Benchmarks for Scientific Literacy (American Association for Advancement of Science [AAAS], 1993) state that, "Students should carry out investigations to become familiar with the pushes and pulls of magnets and static electricity" (p. 27) at the end of 5th grade. State science standards require students to understand the scientific principles guiding the design of a simple electrical circuit by the end of 5th grade.

Twenty five years of research reveals that a significant number of elementary school students do not understand how the fundamental principles of science govern the design and functions of simple electrical circuits. Instead, they rely on their intuitive conceptions and real life experiences to describe the principles guiding the design and functions of a simple electrical circuit (Asami, King, & Monk, 2000; Wandersee, Mintzes, & Novak, 1994). Although these intuitive conceptions and ideas are poorly articulated and often do not reflect the scientific principles of electricity, they have **tremendous** explanatory power for young children (Lee & Yaw 2001; Shaffer & McDermott, 1992; Shepardson & Moje 1999; Planinic et al. 2006; Tsai, 2003). Therefore, these intuitive pre-conceptions can easily interfere with students' learning of scientifically correct principles of electricity when they are in the classroom (Fleer, 1994; Osborne, 1984). In fact, research reveals that students hold onto these conceptions even after they have received explicit instruction on the scientifically correct concepts (Fleer, 1994; Wandersee, Mintzes, & Novak, 1994). Students adhere to their pre-conceptions about electricity and simple electrical circuits partly because classroom instruction that

they receive fails to provide the opportunities for them to reconstruct their pre-conceptions in such ways that are consistent with scientifically acceptable ones (Wandersee et al., 1994). Science education literature blames elementary school teachers' poor knowledge of content and pedagogy for the misconceptions held by many elementary school students (Appleton, 2006; Settlage & Southerland, 2007). The argument holds that many elementary teachers do not have the sufficient subject matter knowledge and pedagogical content knowledge needed for them to teach science concepts in an effective and meaningful way (Appleton, 2006; Fulp, 2002). Instead, they teach the concept of electricity either through reading from the book or through engaging students in hands-on activities that are "fun" but often fail to challenge students to develop conceptual understanding.

Fleer (1994) found that students retained their misconceptions about simple electrical circuits three months after they were instructed on a unit on electricity in a study with young children (5-7). She found that only one third of the 24 students who participated in the study demonstrated the scientifically acceptable understanding of simple electric circuits. In her conclusion Fleer (1994) suggested that elementary school teachers need to examine their curriculum, and their expectations for the students when teaching abstract concepts such as electricity.

The purpose of this study is to explore the effects of a reform-based supplementary kit-based curriculum on 4th grade elementary school children's conceptual understanding of electricity and simple electric circuits.

Students' Misconceptions about Simple Electrical Circuits

Science education literature has identified myriad misconceptions related to elementary school students' understanding of simple electric circuits. The misconceptions that students have about simple electric circuits have been categorized under the following mental models: unipolar model, clashing-currents model, bipolar model, light bulbs creating their own electricity, and attenuation model. Students develop the unipolar model based understanding about electric circuits when they do not have the concept of what a closed circuit is. Chiu and Lin (2004) found that students who held a unipolar mental model considered that "electricity moves from one end of the battery to the bottom of the light bulb to make the light bulb light" (Chiu, p. 445). Students believe that there only needs to be one wire connecting the battery and the light bulb. For instance, when the students are asked to draw an apparatus that would create a lit light bulb, they leave out the wire that connects the bulb back to the battery (Chiu & Lin, 2004).

The bipolar model refers to the idea that two different wires need to be connected to the light bulb to make it light and that the merging of the two wires at the light bulb is what makes it light. The clashing-currents model is a branch of the bipolar model. This model is "where it is recognized that two terminals and two wires are necessary, but not a complete circuit" (Asami et al, 2000, p. 142). Students holding onto this misconception believe that electricity gets completely used up by the light bulb. Within parallel circuits, students that held the bipolar belief thought that the current reaches the two light bulbs,

but does not continuously flow back to the battery. The electricity would be “used up” by the light bulb. Yet again, there is still not a concept of a closed circuit, as with the unipolar model.

The most common mental model that students possess is the attenuation model. The students do have the concept of what a closed circuit is in this model. However, they still believe that electricity can be used up by the light bulb. They also believe that as the electricity travels through the wires it is reduced. It is “where current gets weaker as it passes through successive pieces of the apparatus around a closed circuit” (Asami et al., 2000, p. 142). Thus, within a parallel circuit, students believe that the closer the light bulb is to the battery, the more electricity it will receive and that if there are successive light bulbs, the furthest light bulb would receive the least amount of electricity. Therefore, students may believe that simply having a long wire will make the electric current weaker, since it has to travel further. This also connects to the idea that electricity is unidirectional meaning it only flows in one direction.

Students hold the belief that the battery is the source of energy, or electricity in all of these mental models. They have a materialistic view of what electricity is. It is not a process, but a material provided by the batteries, as “a reservoir for electricity or energy” (Chiu & Lin, 2004, p. 432). Students also hold the belief that electricity is something that can be consumed, or used up. They also do not acknowledge the role of resistance in their conceptions of electrical current.

The scientific model refers to the idea that batteries are the source of electricity, electrical current refers to the movement of (+) charges and electrons are mobile charge carriers and that a force called voltage carries that electricity forward. In addition, it refers to the idea that for charge to flow through a circuit the pathway must consist of conductive materials and that electricity will only flow in a closed circuit. Students should also know about the scientific principles governing the design of simple electrical circuits and understand the difference between them. They need to know that simple electrical circuits are the circuits, which allow only one single path for charge to follow and parallel circuits are the types of circuits in which charge has multiple pathways to follow.

Nature of Physical Science Concepts and Challenges for Students

Physics concepts are harder for students to learn at all levels of education, but they are especially harder for students at the elementary school level than the learning of other physical and life science concepts (Asami et al, 2000; Dharmadasa & Silvern, 2000; Driver & Bell, 1986). There are multiple factors that contribute to the challenge associated with students’ learning of physics concepts. This challenge may be the result of the abstract nature of physics concepts or due to the level of reasoning required for students to understand the scientific principles governing the fundamental physical science phenomena such as electricity (Clements, 1999; Gibbons, McMahon, & Wieggers, 2003; Dharmadasa & Silvern, 2000; Jabot & Henry, 2004; Wandersee, Mintzes, & Novak, 1994). Similarly, psychological development of young students places significant constraints on students’ ability to comprehend the concept of electricity due to level of

complexity needed for students to construct mental models representing such scientific phenomena.

In addition to the abstract nature of physical science concepts and students' psychological development, the mode of instruction employed by the teacher has a significant impact on elementary students' poor understanding of physical science concepts such as electricity (Gibbons et al., 2003; Stohr-Hunt, 1996). Critics maintain that students fail to develop scientifically acceptable understandings about physical science concepts due to behaviorist pedagogies employed by most elementary teachers. They maintain that most elementary teachers primarily rely on readings from the textbook and presentation of abstract information to the students with limited or no reference to the application of the scientific concepts presented to them (Alonzo, 2002; Gibbons et al., 2003; Settlage & Southerland, 2007; Shepardson, & Moje, 1999; Wandersee et al., 1994). Such teaching practices fail to help young children to learn about the physical science concepts (Donovon & Bransford, 2005). Scholars argue because children at earlier ages learn and think through interacting with objects, by making observations and making sense of their observations, they need to learn science through hands-on activities. However, the teacher should scaffold students' learning experiences in these hands-on learning contexts so they can develop scientifically accurate mental models of natural phenomena. Students are likely to develop misconceptions about physical science concepts when taught through behaviorist instructional methods that do not promote sense making or encourage the learners to apply what they learn to real life contexts (Donovon & Bransford, 2005). For instance, literature in science education reveals that students have difficulty learning about the concept of electricity and simple electric circuits when they do not get the opportunity to apply what they learn through lecture presentations and classroom readings (Asami et al, 2000; Gibbons et al., 2003; Settlage & Southerland, 2007).

Although there are some elementary teachers who attempt to teach science through active teaching strategies, their scarce knowledge of physical science places significant limitations on their abilities to teach science in a meaningful and effective way (Alonzo, 2002; Appleton, 2008). This limitation influences how their students conceptualize the scientific principles governing the design and behavior of electric circuits (Gibbons et al., 2003; Henry & Jabot, 2004). In addition to elementary teachers' limited knowledge of science content, naïve pedagogical content knowledge, (Appleton, 2008), the limited number of instructional materials that can help elementary teachers to facilitate students' learning of science through an active mode of learning places limitations on students' learning of electricity and simple electric circuits (Fleer, 1994; Henry & Jabot, 2004).

In this study, the effects of a reform-based supplementary kit-based curriculum on 4th grade elementary school children's conceptual understanding of electricity and simple electric circuits as compared to a traditional hands-on, battery and bulb approach to the teaching of the concept of electricity were examined.

Electrical Studies and Student Learning

Three decades of research suggests that elementary students hold conceptions of electricity and simple circuits that are not consistent with the scientific ones. The same literature point out that helping students to reconstruct their intuition-based conceptions of electricity and empowering them to develop scientifically acceptable conceptions of electricity mandates that students learn about the concept of electricity and simple circuits through hands-on and minds-on learning activities (Fleer, 1994; Gibbons et al., 2003). Jaakkola and Nurmi (2007) state:

Since intuitive conceptions are grounded in personal experience, educational environments should expose students to re-experience the phenomena, help them to recognize the conflict between their prior knowledge and new concepts, and support them during the demanding process of conceptual change. (p. 1).

In fact, science education literature confirms the effectiveness of hands-on learning activities on students' learning of science concepts through empirical evidence. In a study that looked at the effects of hands-on science activities on 24, 599 eighth-grade students' learning of science Stohr-Hunt (1996) found that students who frequently engaged in hands-on science learning activities showed significantly higher levels of science achievement than those who did not. In another comparative study that looked at the effects of inquiry-based instruction on middle school students' performance on standardized tests. Ruby (2006) found that test scores of students using the inquiry-based science programs were higher than those of the students who were exposed to traditional instruction.

Young and Lee (2005) looked at the influence of hands-on learning activities on 399 5th graders' science achievement and found that the students who received hands-on instruction scored significantly higher than the students who received traditional forms of instruction. A meta analysis of 57 studies on the effectiveness of activity-based curricula revealed a 14 percentile difference between the students in the activity-based programs versus students in traditional programs, with students in the activity-based programs scoring higher than the students in traditional instruction (Bredderman, 1983). In a similar study, Shymansky, Hedges, Woodworth and George (1990) analyzed 81 research studies that compared science achievement of students in the traditional lecture based classrooms to the achievement of students in classrooms in which the instructors used hands-on activities as primary form of instruction. Shymansky et al., (1990) concluded that students in classrooms where teachers used activity-based, hands-on learning methods of teaching performed better than those in the traditional classrooms. Furthermore, they found that activity-based method of teaching had greater affect on female students and students coming from minority and socioeconomically disadvantaged backgrounds.

Such active learning experiences are needed not only for students to develop scientifically acceptable conceptions about the concept of electricity and simple electric circuits (Gibbons et al., 2003; Limon & Mason 2002; Treagust, Duit, & Nieswandt, 2000) but also for students to experience and understand how scientists come to understand

physical and natural phenomena (NRC, 1996). If scaffolded properly, activity-based learning experiences can engage students in meaningful observations, hypothesis development, testing of their hypothesis and data collection and interpretation. Moreover, proper scaffolding can engage students in collective knowledge construction activities, a central element of how scientists come to generate new knowledge (NRC, 2000).

Although activity-based instruction is the most appropriate mode of instruction for elementary school children's development of scientific understanding of key physical science concepts (Schneider, Krajcik, Marx & Soloway, 2002), engaging students in hands-on activities alone is not sufficient for learning to take place. In order for such learning activities to be effective and contribute to students' learning of science concepts, the purpose of hands-on activities must be explicit to the teachers and students at the elementary level (Settlage & Southerland, 2007). Furthermore, instructional materials must be designed to decrease the amount of frustration that the elementary school teachers have with the teaching of science (Settlage & Southerland, 2007).

This observation calls for development of instructional materials that emphasize students' deep understanding of essential scientific principles and epistemologies of science, rather than instructional materials that simply allow students to interact with objects and play around to have fun. Too, it calls for the use of kit-based curriculum that encourages teaching strategies that will properly guide students' thinking and provide challenge for students to continuously engage in a search for meaning.

Background Information on Kit-Based Curriculum Materials

History of kit-based curriculum materials dates back to 1960's when the launch of Sputnik motivated the federal government to sponsor the development of reform-based, hands-on curriculum materials (Settlage & Southerland, 2007; Young, & Lee, 2005). Although teachers mostly rely on textbooks to scaffold science instruction, kit-based curriculum materials are now commercially available. These kit-based curriculum materials are designed to help elementary school teachers to engage students in the learning of science, to stimulate their interest in science and to help their students to connect what they learn in lectures to their everyday life (Gibbons et al., 2003; Henry & Jabot, 2004; Settlage & Southerland, 2007). However, previous research shows that not all hands-on activities lead students to develop conceptual understanding.

Settlage and Southerland (2007) argue "people are often drawn into the idea that doing activities is all that is required for good science teaching" (p. 217). They maintain that many teachers consciously or unconsciously confuse emotional engagement with intellectual engagement and equate excitement with learning. Moscovici and Nelson (1998) point out that equating students' overexcitement while doing science activities with learning reflects a naïve understanding of the nature of students' learning. These scholars state that although students' emotional engagement in the learning of science is crucial, such engagement is not sufficient for students to develop scientifically acceptable understanding of essential scientific principles. Settlage and Southerland (2007) argue, the culture of science involves engaging students not only in doing of activities and

absorbing scientific information but also engagement in cognitive actions that engages students into “ways of thinking that are distinctive to science” (p. 217).

It follows that in order for kit-based curriculum materials to ensure and enhance students’ learning along the lines of inquiry and contribute to their conceptual understanding of scientific ideas presented in school curriculum, they must give students the opportunity to question, to observe, to think and to argue about the scientific concepts under investigation (Settlage & Southerland, 2007; Stohr-Hunt, 1996). Only then students may be able to develop scientifically acceptable understandings about the design and behavior of simple electric circuits.

These findings and suggestions from three decades of research on students’ misconceptions about electricity at all levels of schooling and limitations of previous kit-based science curriculum has encouraged science educators to rethink about curriculum and instruction (Fleer, 1994; Henry & Jabot, 2004). Research findings that document elementary school teachers’ lack of confidence in teaching of science, also motivated curriculum developers to design kit-based science teaching materials (Gibbons et al., 2003; Settlage & Southerland, 2007; Stohr-Hunt, 1996). A variety of new kit-based curricular materials have been developed as a result of this rethinking about how to best teach students about science especially at the elementary level. The primary purpose of these kit-based materials is to provide students with the physical means needed for them to investigate the phenomena of electricity through active manipulation of materials, as well as to provide students with experiences that are scientifically acceptable, thus help them to eliminate their intuition-based understanding of electricity (Holohan & Deluca, 1995; Settlage & Southerland, 2007).

In this study, the impact of a reform-based science curriculum called *The Electric Circuits Kitbook* on 4th grade elementary school children’s conceptual understanding of simple electric circuits were examined.

Electric Circuits KitBook

Edamar has developed a supplementary kit-based curriculum unit on simple electric circuits, called the *Electric Circuits KitBook* (EC KitBook) to make the teaching of the scientifically acceptable theories about simple electric circuits easier for elementary school teachers. More information can be found at www.kitbook.com. *Electric Circuits KitBook* differs from the traditional methods of teaching hands-on science lessons in that they contain all the physical and instructional materials needed to meet the national and state standards for the topic of interest (Edamar, 2007). Edamar developed *The Electric Circuits KitBook* so that the hands-on activities can be reliably and safely completed by students right in the book. This self-contained nature of *Electric Circuits KitBook* makes it easier for teachers to scaffold instructional activities and allows the teachers to spend less time on safety concerns and the laboratory set-up, thus spend more time on science instruction compared to a traditional method of instruction. The *Electric Circuits KitBook* meets the quality criteria established by The Project 2061 Curriculum Standards in the judgment of the author.

The Project 2061 Curriculum Standards identify a curriculum to be reform-oriented if:

Curriculum starts with ideas that are familiar or interesting to the students, explicitly conveys a sense of purpose; takes into account student ideas and conveys suggestions for teachers to find out what their students think about the phenomena related to the benchmark; provide hands –on experiences with phenomena; and has students represent their own ideas about phenomena and practice using the acquired knowledge and skills in varied context (Kesidou, Roseman, 2002 as cited in Lynch, Taymans, Watson, Ochsendorf, Pyke, & Szesze, 2007, p.206).

Electric Circuits KitBook was developed based on an active model of learning that includes three phases; concept development, exploration and explanation. Students first learn the fundamental scientific language skills needed to understand the phenomena of electricity. Language acquisition skills include, acquiring vocabulary and learning definitions of key concepts through memorization and practice. Acquiring the scientific vocabulary and learning the definitions are very critical for students to be able to participate in discussions about science. Then, students are given the opportunity to explore how electric circuits work through a set of hands-on activities. KitBook activities also give students the opportunity to make a connection between their everyday lives and the fundamental laws of physics governing the phenomena of electricity and the design of simple electric circuits. Finally, students are challenged through assessment items to translate what they learn during the exploration phase into conceptual understanding by reflecting on their experiences. Assessment questions target four key skills; language acquisition, conceptual understanding, critical thinking, and writing skills.

The *Electric Circuits KitBook* challenges students to think critically about the concept under investigation both during and after each activity. The *Electric Circuits KitBook* questions challenge students to think at a higher level and create opportunities for students to discuss questions with one another and come up with conclusions that they may never find in the book. Although the activities reflect certain features of inquiry, there are certainly some limitations of kit-based activities in terms of their abilities to reflect the authentic nature of scientific inquiry. However, in the author's judgement the *Electric Circuits KitBook* promotes students' acquisition of scientific inquiry skills to the maximum extent possible without sacrificing safety.

Electric Circuit KitBook Activities

Electric Circuits KitBook is designed to engage students in nine different learning activities. Each activity in the *Electric Circuits KitBook* reinforces different national and state science objectives. Tennessee state science standards were used to illuminate the alignment between *Electric Circuits KitBook* activities and state science standards. Tennessee state science standards are emphasized because this study took place in the state of Tennessee. Therefore, when working with the participating teachers the author asked the teachers to complete only the first five activities. The TN 4th grade state science standards that focus on the concept of electricity are summarized in the following table.

Table I

TN Standards for 4th grade Science. Content Standard 14: Energy: Electricity

Learning Expectations	Students will be able to recognize the basic concept of electricity.
Accomplishments	a. Construct and explain a simple electrical circuit. b. Categorize materials as conductors or insulators.

Table II

Alignment between Electric Circuit Kitbook and State Science Standards.

KitBook Activity	Learning Objectives	TN 4 th Grade Science Standards
Simple Circuits	<ul style="list-style-type: none"> Students will be able to identify the three parts of a simple electric circuit Describe the difference between an open and closed circuit. 	X
Batteries	<ul style="list-style-type: none"> Students will be able to describe how battery power affects the device it is supplying electricity to. 	X
Conductors and Insulators	<ul style="list-style-type: none"> Describe the differences between electrical conductors and insulators. Identify electrical conductors and insulators through experimentation Describe why it is important to have both conductors and insulators. 	X
Switches	<ul style="list-style-type: none"> Identify three parts of a switch Describe how to put the slide and push-button switches in the ON and OFF position. 	X
Series Circuits	<ul style="list-style-type: none"> Students will be able to describe the features of series circuits Construct a series circuit and trace the current path. 	
Parallel Circuits	<ul style="list-style-type: none"> Identify parallel circuits Construct parallel circuits and trace the current paths. 	
Electromagnetism	<ul style="list-style-type: none"> Describe how an electromagnet works. Construct a working electromagnet. Discuss the useful applications of electromagnets. 	

Although there are nine different *Electric Circuits KitBook* activities only four of these activities correlate with Tennessee's 4th grade science standards and the rest of activities correlate with grades 5 and 6 science standards.

Methodology

This study is an intervention-based case study and compares the learning outcomes of two groups of students; treatment and control. Data were collected through administration of a post conceptual test called The *Electric Circuits Concept Inventory Test* and classroom observations. Both quantitative and qualitative methods were used for the analysis of data.

The subjects selected for this study include 100 4th grade elementary school students ranging from 10 years to 12 years in age, enrolled in two different public school systems in a southeastern state in the U.S. The student population at the schools where the sample was drawn has increasingly become diverse culturally, linguistically and socioeconomically in recent years due to nationwide immigration patterns. The sample was purposefully selected from schools that hosted students with similar reading scores on the state standardized test. This is to minimize the effect of students' reading proficiency on their performance on the *Electric Circuits Concept Inventory Test*. The *Electric Circuits Concept Inventory Test* is the test the first author developed and used to measure students' learning of electricity and simple electrical circuits.

The sample was drawn from six classrooms from two different school systems. Three classrooms were randomly assigned as the control group and the other three classes were randomly assigned as the treatment group. The treatment group studied the *Electric Circuits KitBook* for 30 minutes a day over one week period of instruction. The students in the control group studied the same unit through traditional methods; reading a text, classroom lectures, teacher demonstration and a hands-on activity that used a battery and a bulb. The time spent on the concepts both in the control group and treatment group was approximately the same. In an effort to measure students' knowledge of the concepts covered by the TN state science standards the *Electric Circuits Concept Inventory Test* was administered to all students in both the treatment and control groups. The test was administered to the students one week after the instruction took place. Students' posttest scores were used as a measure of their understanding of the concepts covered by the State of Tennessee Science Standards on Electricity for 4th graders and thus the impact of *Electric Circuits Kitbook* on students' conceptual understanding of electricity and simple electrical circuits.

Data Sources

Data sources consisted of students' responses to the *Electric Circuits Concept Inventory Test* and classroom observations. The details of the *Electric Circuits Concept Inventory Test* and the way it was administered are provided in the following sections.

The rationale for conducting classroom observations as part of data collection process is also mentioned in the following section.

Instrument: Electric Circuits Concept Inventory Test

The author developed a multiple-choice assessment instrument to measure students' understanding of key concepts about electricity and simple electrical circuits covered by the state of Tennessee science standards. The assessment items were carefully designed to reflect the learning objectives reinforced by the state standards. The choice of using the learning objectives reinforced by the state standards is to accurately measure the impact of *Electric Circuits KitBook* on students' acquisition of key concepts covered by the state of Tennessee science standards.

The choice of multiple choice assessment questions over open-ended questions stems from the fact that the former makes it easier for the researcher to eliminate the assessor bias attached to the grading of open-ended type assessment questions. Another factor that encouraged the author to use multiple-choice questions is the wide use of multiple-choice tests for measuring students' learning outcomes by many states in this age of accountability.

Classroom Observations

It is important to understand the pedagogical discourses in both the treatment and control classrooms before presenting the argument on the effectiveness of the *Electric Circuits KitBook* on students' understanding of electricity and simple electric circuits. As such information is critical in helping us to understand the differences and similarities in the instructional approaches followed in both control and treatment classrooms. The researcher observed each classroom and took field notes four times a week during the implementation of the *Electric Circuits KitBook*. The purpose of classroom observations was to provide a detailed account of the pedagogical context in which the study took place. The researcher paid specific attention to the mode of instruction that took place, time spent on the use of *Electric Circuits KitBook* and the power relationships between the teacher and the students. Also, classroom observations enabled the researcher to document students' pre-conceptions about simple electrical circuits. These observations were recorded in a researcher journal and were then used to support or reject the assertions emerged from the analysis of quantitative data related to students' conceptual understanding of simple electrical circuits.

Data Analysis

Data analysis took place in two steps. First, data on classroom observations were analyzed to provide a description of the pedagogical discourses in which the learning took place. Second, the quantitative data gathered through *Electric Circuits Concept Inventory Test* were analyzed. Students' responses to the *Electric Circuits Concept Inventory Test* were divided into the following three different categories based on TN state science standards for 4th grade students. The TN standards for 4th grade science about electricity state the following.

1. Students will be able to recognize the basic concept of electricity.
2. Students will be able to construct and explain a simple electrical circuit.
3. Students will be able to categorize materials as conductors or insulators.

Student's responses for each question on the test were analyzed independently and the percentage of correct answers for each item on the test was calculated. These percentages related to the three different categories mentioned above are reported in the findings section. Then, an independent t-test was run to compare the mean scores of the two groups of students on the *Electric Circuits Concept Inventory Test*. A set of assertions about the impact of the *Electric Circuits KitBook* on 4th grade elementary school children's understanding of simple electric circuits were developed based on the analysis. Classroom observations were used either to support, refine or confront the initial assertions. Since the treatment group outperformed the control group the discussion of the pedagogical discourses is limited to the treatment group classrooms only.

Findings

Findings are reported in the following manner. The findings for the entire sample are reported first, followed by case-by-case analysis of each set of questions that correlate with each state standard described in Table II.

The post-test scores were analyzed using descriptive statistical analysis. The learning outcomes of the treatment group students were compared to those of students in the other three matched control classrooms. The following graph, Figure A indicates how each group performed on each question on the test.

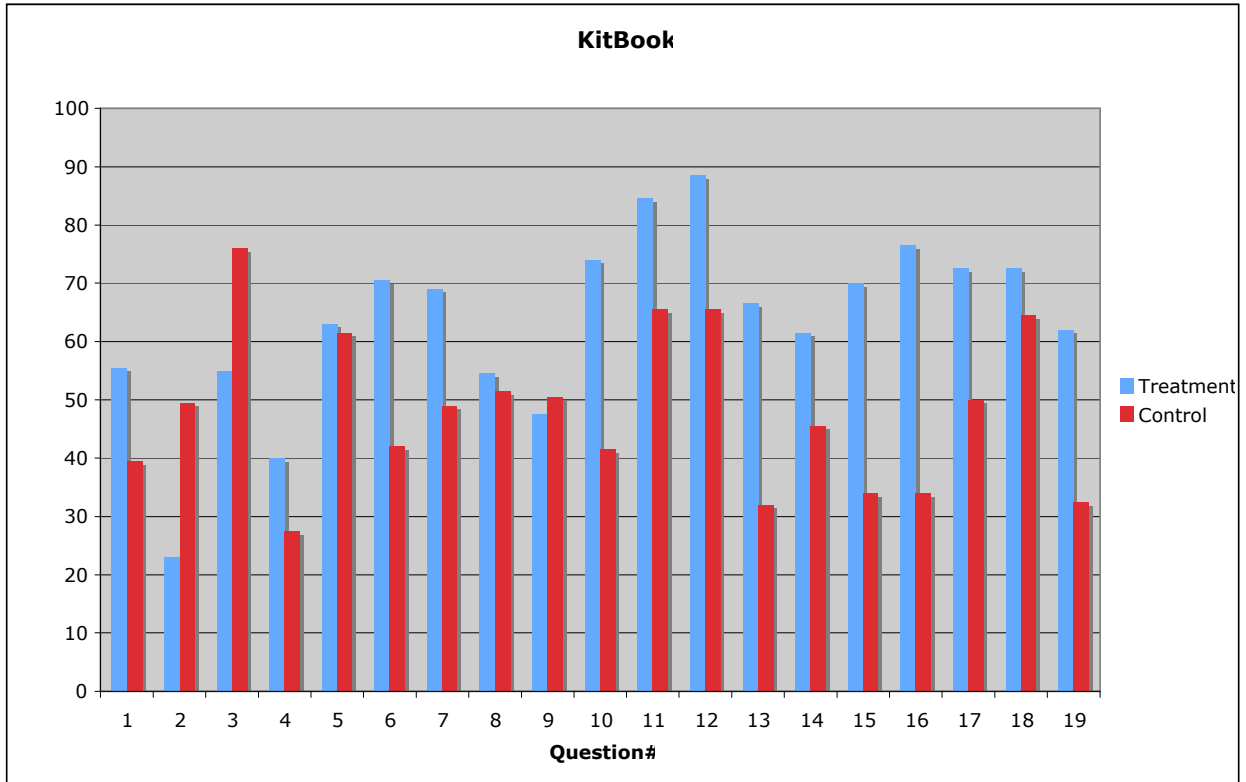


Figure A. Treatment and control groups’ performance comparison.

As the Figure A indicates, students in the treatment group outperformed the students in the control group significantly on 13 of the 19 questions. The difference in the achievement of the two groups is more obvious when the percent correct answers of each group are compared. Such comparison has been displayed in Table III.

Table III
Treatment and Control Group Performance Comparison Table: Raw Data

Question #	Treatment (n=50)	Control (n=49)
1.	55.5	39.5
2.	23	49.5
3.	55	76
4.	40	27.5
5.	63	61.5
6.	70.5	42
7.	69	49
8.	54.5	51.5
9.	47.5	50.5
10.	74	41.5
11.	84.5	65.5
12.	88.5	65.5
13.	66.5	32
14.	61.5	45.5
15.	70	34
16.	76.5	34
17.	72.5	50
18.	72.5	64.5
19.	62	32.5

In addition to comparing the mean performance of each group of students on the *Electric Circuits Inventory Test* question by question, the questions were correlated with the state science standards to make the results meaningful. Table IV describes the correlation between the questions on the *Electricity Concept Inventory Test* and the state of Tennessee curriculum standards for 4th grade science. This table not only gives the readers the ability to compare the individual questions to the state science standards but also it makes the reading of the findings much easier. This comparison has been provided in Table IV.

Table IV
Correlation Between Test Items and TN Science Standards

Content Standard: 14.0: Energy: Electricity		Corresponding Questions
Learning Expectations	Recognize the basic concept of electricity.	3,6, 9, 11,12, 15
Accomplishments	a. Construct and explain a simple electrical circuit.	1, 2, 5,6,7, 8,10, 13, 14, 19, 18
	b. Categorize materials as conductors or insulators.	4,16, 17
Learning Expectation	Safety	12

The first standard that the students' conceptual understanding was tested on emphasized students' ability to recognize the basic concept of electricity. The details are given in Table V. The analysis indicates that the treatment group students outperformed the control group students on four of the six questions under learning expectations. The treatment group students outperformed the control group students by 28.5 points on question number 6, by 19 points on questions number 11, by 23 points on question number 12, and by 36 points on question number 15. The control group students outperformed the treatment group only on question number 3 by 21 points. Although the control group students outperformed the treatment group students by 3 points in question number 9 this difference is not significant.

Table V
Learning Expectation#1: Comparison on learning expectation: Recognize the basic concept of electricity.

Question #	Treatment	Control	Difference in percentages
3		√	21 points
6	√		28.5 points
9	—	—	3 points
11	√		19 points
12	√		23 points
15	√		36 points

√=Treatment group performed better, —= no significant difference between groups,
 √= Control group performed better.

The second standard that students' conceptual understanding was tested on emphasized students' ability to construct and explain a simple electrical circuit. The

analysis indicates that the treatment group students outperformed the control group students on 9 of the 11 questions under the learning expectation: construct and explain a simple electrical circuit. The control group students outperformed the treatment group students only on question number 2 by 21 points. Although the treatment group students outperformed the control group students on question number 5 by 1.5 points and by 3 points on question number 8, this difference is not significant. The two questions in which the control group students outperformed the treatment group students focused on students' ability to recall information. For instance, question # 5 asked students the parts of a simple electric circuit that enabled the electric current to flow and question #8 asked students to identify the part of a simple electrical circuit that controlled the flow of electricity.

Table VI
Learning Expectation#2

Comparison on learning expectation: Construct and explain a simple electrical circuit.			
Questions #	Treatment	Control	Difference in percentages
1	√		16 points
2	√	√	26.5 points
5	—	—	1.5 points
6	√		28.5 points
7	√		20 points
8	—	—	3 points
10	√		32.5 points
13	√		34.5 points
14	√		16 points
18	√		8 points
19	√		29.5 points

√=Treatment group did better, —= no significant difference, √= Control group performed better.

Students' performance on questions that emphasized the third standard, students' ability to categorize materials as conductors or insulators was also compared. There were three questions on this standard. The treatment group students outperformed the control group students on all three questions on this standard.

Table VII
Learning Expectation#3

Questions #	Treatment	Control	
4	√		12.5 points
16	√		42.5 points
17	√		22.5 points

√=Treatment group performed better, —= no significant difference between groups,
 √= Control group performed better.

Finally, the treatment group and control group students' understanding of safety was compared by analyzing their responses to the question number 12. The findings indicate that the treatment group students outperformed the control group students by 23 points on safety question.

Table VIII
Learning Expectation#4

Comparison on learning expectation: Safety			
Questions #	Treatment	Control	Difference in percentages
12	√		23 points

The results of the test of significance on the performance of the treatment and control group students on the *Electricity Concept Inventory Test* are presented in the next section.

T-Test Results

The following tables provide the statistical analysis of the difference between the treatment group and the control group students.

Descriptive Statistics. The descriptive statistics reveal that the mean of treatment group students is 29.10 points higher than the mean of control group students. This difference is large and statistically significant. The statistics for this comparison are given in Table IX.

Table IX
Descriptive Statistics

Group	N	Mean	SD	SE
Treatment	50	70.10	15.99	2.26
Control	50	41.00	16.60	2.34

As these group statistics indicate the mean of treatment group students is 19.10 points higher than the mean of control group students. The statistical significance of these results is shown below.

Independent Samples T-Test. The t-test is significant at level of $\alpha=0.005$ (0.5%) with p-value of less than 0.001. This clearly indicates that the treatment group mean is significantly higher than the control group mean. Overall, the students who learned the concepts of electricity and simple electric circuits through *Electric Circuits KitBook* outperformed the students who were randomly assigned to the control group (see Table X)

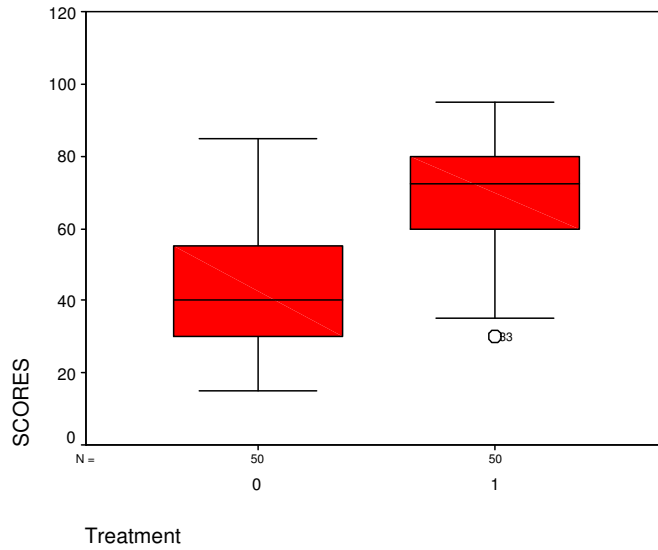
Table X
Independent Samples T-Test for KitBook

Mean Test Scores	Levene's Test for Equality of Variances		T-test for Equality of Means						
	F	Sig.	t	df	Sig.	Mean	Std.	95% Conf. Int.	
						Difference	Error	Lower	Upper
	0.142	0.71	8.93	98	< 0.001	29.10	3.26	22.63	35.57

The t-test is significant at level of $\alpha=0.005$ (0.5%) with p-value of 0.001. This clearly indicates that the treatment group mean is significantly higher than the control group mean. Overall, the students who learned the concepts of electricity and simple electric circuits through the *Electric Circuits KitBook* outperformed those who were randomly assigned to the control group.

Box Plot. The box plots (1 = treatment and 0 = control group) suggest that mean performance scores are comparable between the treatment and control groups. The sample variability within each group looks similar; there is only one outlier in the treatment group (with a lower score). The median score for treatment group is clearly higher than the median score of the control group (score range is 0 to 95 for 19-question test).

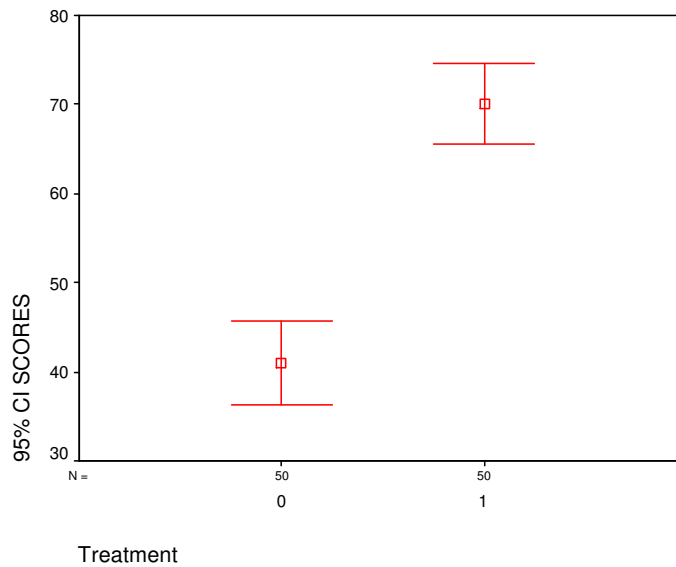
Figure . Error Bar Plot



Error Bar Plot

The graph shown below (1 = treatment and 0 = control group) shows the confidence intervals for treatment and control group means separately.

Figure C. Error Bar Plot



According to the error bar plot of the means and their Confidence Intervals (shown above), it is clear that the confidence intervals do not overlap at all. This indicates a significant mean difference between the treatment and control groups. According to the plot, the treatment group has a higher mean, 70.1, than the control group with a mean of 41.0. The sample variability within each group looks similar. This empowers the confidence in the interpretation of the differences between the two groups.

Effect Size

The effect size was calculated using Cohen's *d* formula as the ratio of the mean score difference between treatment and control groups to the pooled standard deviation. The effect size was 1.79, which is considerably large (large effect ≥ 0.8) enough to allow us to make the judgment that *The Electric Circuits Kitbook* had a significant impact on 4th grade elementary school students' learning outcomes. Although the quantitative data analysis suggests a significant difference between the treatment group and the control group it is imperative to provide the readers with additional information about the pedagogical discourses in which the treatment group students learned science. Such information will empower the readers to make sense of the findings reported in this paper.

Pedagogical Discourses: Treatment Group Teachers

Two treatment teachers and three classrooms that they taught were chosen to understand the impact of *Electric Circuits KitBook* on students' understanding of simple electric circuits and electricity. The following is a brief description of the pedagogical approaches adopted by each of the treatment group teacher (Teacher A and Teacher B).

Teacher A followed an authoritarian instructional methodology that used motivational prompts to engage students in the discussion of electricity. The teacher started the lesson by asking, "why do we want to learn science" after asking students to look at the picture of a space shuttle on the first page of the *Electric Circuits KitBook*. One student said, " maybe so we can be part of the space mission" Another student looked at the space shuttle picture and said, " it probably has a lot of parts." As this dialogue shows, the teacher asked these questions to secure students' emotional interest in the subject and to help them make connections between real life and the content of her lesson. Teacher A integrated reading comprehension skills in her instruction with the *Electric Circuits KitBook*. The teacher started reading the chapter one and made students to take turns and read the first chapter. The teacher asked the students to look around the room and identify parts that they thought used electricity. Students were able to identify the parts. They said, " TV, projector, bulbs" and one student said, " we have a telephone that works on batteries so when the power is out it still works". The teacher then asked, "What will happen if we cut the electricity?" Students responded, "the lights would go out, we will not have the heat, people in the lunch room would not be able to cook our lunch. Speakers would not work." Teacher A also used analogies to help her students to understand the concept of electricity. For instance, Teacher A used the football analogy to explain how the current flows through the wires. She said, "electricity flows through the least resistant regions of the wires. It is like a football player running the ball on the

field. What do they do? They always look for an open line to run, right?” Then, the teacher asked her students to look at the pictures of a closed and open circuit in the Kitbook and explained the difference between the two. The teacher asked her students, “Why do you think copper is used in electric circuits? One student said, “Because it is easier to find”. The rest of students said, “No, no... because it is metal,” One student said, “anything metal will conduct electricity.”

Girls appeared to be more excited than the boys did when the instruction took place through dialogue between the teacher and the students. They felt very powerful in terms of expressing what they knew about science. In addition, they appeared to be very excited about learning science through the hands-on approach used by the *Electric Circuits KitBook*. Students’ excitement of learning science may in part be attributed to the fact that the *Electric Circuits KitBook* made the acquisition of factual knowledge about circuits visible to the students through visuals but also because it made application of such knowledge possible as students responded to teachers’ leading questions and constructed simple circuits using two bulbs and a buzzer. Testing out different Kitbook activities helped students to develop curiosity about the concept of simple circuits. This may have empowered students to learn about science and continue to show more interest in learning of science. For instance, students put the batteries of two kitbooks together to make the fan spin faster as a result of such curiosity. It is unlikely that students would have had such opportunities to test out their curiosities if they were to learn science through traditional science instruction that simply relies on one bulb and batteries.

Students’ Prior Knowledge

The findings from classroom observations are consistent with previous research, which shows that students come to science classrooms with a wide range of ideas and conceptions often drawn from their everyday life experiences (Asami et al, 2000; Osborne, 1981). However, the conceptions and ideas that students bring with them to the classroom often fail to reinforce scientifically acceptable views (Limon & Mason 2002). Although the knowledge that students brought with them to the classroom was relevant in the context of this study, such knowledge was stripped from a theoretical framework and a scientifically acceptable mental structure for explaining the concept of electricity or of the scientific principles guiding the design of a simple electrical circuit. The knowledge that the students brought with them to the classroom included examples. For instance, students gave examples of devices that use electricity and emphasized the safety concerns related to using such devices. When the teacher was going over the safety, one student said, “do not mix electricity with water because you will get electrocuted.” Another student said, “do not pour a hairdryer in the water when you dry your hair.” Another student said, “people did it for us? Some people did what we should not be doing”, referring to the precautions needed for handling the electrical devices safely. So there was no evidence of prior knowledge that emphasized the scientific principles guiding the design and functions of simple electrical circuits.

The pedagogical discourse in the second case (*Teacher B*) reflected the essential features of guided inquiry. Guided inquiry has been defined as a balance between student-directed and teacher-directed learning (NRC, 1996). In a guided inquiry

framework Although students are engaged in scientific investigations, teacher provides a structure for students to pursue their investigations by by helping them to collect and analyze data, form explanations and communicate their explanations using multiple means such as writing and talking (NRC, 2000). Although the teacher did not ask her students to collect data she challenged them to answer critical questions that she asked of them. An example of such question includes, “Can you tell me how the electricity travels through the wire? And what happens to it once it reaches the bulb?” Teacher B supplemented her instruction with internet-based scientific visualizations on electricity, as her classroom was well equipped with technology. Her instruction also differed from Teacher A in that she used collaborative group work rather than teaching through telling and reading. She assigned specific questions to the students and asked them to work on the questions from the *Electric Circuits KitBook* in groups of two. She then walked around the room asked her students both leading and probing questions about the activities that they were completing from the *Kitbook*. The comparison of the scores of students of these two treatment group teachers showed a difference with the students of Teacher B performing better than the students of Teacher A. However, the difference was not statistically significant. For instance, the number of students who accurately draw a simple circuit were higher in the classroom of Teacher B than there were in Teacher A’s classroom.

Discussion

Previous research reveals that explicit instruction helps students to overcome the limitation of their preexisting mental models of simple electrical circuits (Asami et al, 2000). However, in order for students to develop scientifically acceptable mental models about the concept of electricity and simple electric circuits, students need to test their ideas or ideas that are presented to them through hands-on learning activities. Moreover, the teacher needs to challenge students through formative assessment prompts to develop scientifically acceptable explanations about a science topic studied through hands-on activities.

The findings from this study indicate that the *Electric Circuits KitBook* helps 4th grade elementary school students to develop conceptual understanding of simple electrical circuits and electricity as evidenced in t-test results. This result can be attributed to three things. First, the *Electric Circuits KitBook* activities created opportunities for students to learn science through doing. Second, the layout of the platform that enables students to try out different activities makes the design of simple electrical circuits and the notion of closed circuit visible to the students. This, the *KitBook* assessments challenge students to test their answers by completing multiple set of activities. Finally, it challenges students to write about their learning.

Although the *Electric Circuits KitBook* appears to be promising in helping students to develop conceptual understanding, whether students will be able to develop conceptual understanding or not depends on the teacher. If the teacher uses *KitBook* activities simply and only to make science learning fun for his/her students, students are unlikely to develop conceptual understanding by completing the *KitBook* activities. As evidenced in the Teacher A’s case, reading, lecture and worksheet activities do not help

students at the elementary school level to develop scientifically acceptable conceptions about electric circuits (Asami et al, 2000; Bredderman, 1983; Stohr-Hunt, 1996). Classroom observations of Teacher A, who taught through *The Electric Circuits KitBook* in the first stage of the study indicate that the teacher failed to successfully provide the scaffolding needed for her students to develop conceptual understanding. Although the teacher used an interactive teaching method, she did not hold her students accountable for providing evidence-based explanations. Most questions were of recall type. In addition, the teacher feedback was in the form of praise rather than providing further challenge for students to justify their answers or provide more in-depth explanations.

The influence of the form of instruction used by the Teacher A was reflected in students' answers. For instance, although her students were able to answer recall questions with 90% to 100% accuracy, the percentage of students who were able to answer interpretation or application questions remained relatively low, yet still better than those in the control group. Although the teacher was able to ensure that students knew the idea that in order for a simple electrical circuit to work the circuit must be a closed circuit, the teacher did not help her students to develop their understanding of electricity around a coherent content storyline. The content story line may provide scaffolding needed for students to use piecemeal information, integrate that information to develop global understanding about simple electric circuits. This issue arose simply because the teacher did not engage her students in discussions and failed to provide the criticism needed for the students to justify their answers and thus to develop such understanding. As evidenced in this case although inquiry-based curriculum materials hold potential to help students develop scientifically acceptable theories about the phenomena of electricity (Dalton et al., 1997; Gibbons, McMahon & Wieggers, 2003; Wandersee et al., 1994) using an inquiry-based curriculum alone is not sufficient. In order for such curriculum materials to be effective in helping students to develop scientifically acceptable conceptions of simple electrical circuits, they must be used in a manner that is consistent with methods of inquiry.

Asami et al. (2000) maintain, students' understanding of electrical circuits is related to students' level of cognitive processing. This implies that the teacher must scaffold instruction through questioning, leading questions and constant feedback to accelerate students' cognitive processing skills for optimum results. Gibbons et al. (2003) maintain that in order for the elementary school teachers to teach electric circuits in an effective manner they need to become acquainted with the body of educational research that document students' misconceptions about electrical circuits. The results of this study support Gibbons et al's (2003) argument. Having knowledge of students' misconceptions related to simple electrical circuits and using methods of instruction consistent with the principles of conceptual change theory holds potential to help elementary school teachers to scaffold instruction through lenses of student thinking and to help their students to develop scientifically acceptable theories about simple electrical circuits. Although the students who learned the concept of electricity and simple electrical circuits through *the Electric Circuits KitBook* outperformed those that learned the same concepts through traditional instructional methods, the curriculum itself alone cannot account for the differences in students' test scores. The results of classroom observations highlight the importance of the teacher and the scaffolding provided by the teacher in students'

learning gains. The researcher gave the treatment teachers the guidelines for scaffolding instruction through the lens of guided inquiry. While Teacher B successfully implemented instructional methods informed by the principles of guided inquiry, Teacher A failed to follow the guidelines thoroughly. As a result, the students of Teacher B performed better than those of Teacher A on conceptual questions. This finding is consistent with the findings of previous studies (Carlone, 2004; Roehrig, & Kruse, 2005) and highlights the role that a teacher can play in implementing the goals of a reform-based science curriculum. It is well documented in science education literature that elementary teachers fail to implement the goals of a reform-based curriculum due to the lack of content knowledge and pedagogical content knowledge (Appleton, 2008). This calls for science teacher educators to pay special attention to the content of their elementary science methods courses (Abell, Appleton, & Hanuscin, 2009). Traditionally, elementary methods courses focus on teaching teacher candidates how to teach science. Perhaps we need to place an increasing emphasis on these elementary teacher candidates' conceptual understanding of key science concepts (AAAS, 1993) that they are expected to teach once in the classroom. An improved understanding of content is likely to help elementary school teachers to develop sophisticated pedagogical content knowledge needed for them to teach science for conceptual understanding (Appleton, 2006). Similarly, such knowledge may also help them to implement reform-based curriculum materials in an effective manner.

Limitations

Several limitations of this study must be acknowledged. The first limitation deals with the methodology used to gather information about students' understanding of electricity and simple electric circuits. Making general judgments about students' understanding of electricity and simple electrical circuits only through a multiple choice test cannot fully account for what a student knows about the concept of electricity. In order for the researchers to adequately document what a student knows about the phenomena of electricity and simple electrical circuits, their answers to a multiple choice test must be supported by their answers to open-ended questions that can be gathered through student interviews. Only then, we may be able to understand whether *Electric Circuits Kitbook* helped students to develop conceptual understanding or not. Although probing students' conceptual understanding of simple electric circuits through interviewing is preferable over the multiple-choice test method, the author lacked financial resources to conduct such an investigation. However, such limitation serves as a venue for further investigation into the elementary school children's understanding of simple electrical circuits. The second limitation deals with the type of instruction that the students received from their teachers. Classroom observations indicate that teachers used different instructional methodologies both in the treatment group classrooms and in the control group classrooms. Although variability is spread out across the sample teachers, acknowledging such variability empowers the readers to interpret the results of the study. Finally, the treatment group teachers did not fully follow the teaching guidelines that were provided to them. This might have placed limitations on the reported students' learning gains. It is possible that the students in the treatment group could have performed better on *The Electric Circuits Inventory Test* had the treatment group teachers strictly followed the guidelines provided by the author. For instance, teachers chose to

assign only select questions from the students' workbook as homework to their students instead of holding them accountable for answering all of the questions. It is likely that such selectivity had a negative influence on the treatment group students' learning gains. If such variables can be controlled in an effective manner in the future studies, we will have a better understanding of the impact of reform-based curriculum on students' conceptual understanding.

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