ACADEMIC IMPACT OF LEARNING OBJECTS: THE CASE OF ELECTRIC CIRCUITS

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Abstract

Electricity is an important and challenging science topic at all school levels. Learners often have many difficulties in learning electricity. Previous attempts to overcome these difficulties have been rather one-sided, leaning only on one method at the time, and thus ineffective. As a solution, a learning environment which combines the strengths of traditional laboratory exercise and simulation working with tasks that structure student work and explicitly address common difficulties in learning electricity was developed. This experimental study examined if this 1) simulation-laboratory-combination environment can enhance elementary school students understanding of simple DC circuits compared to those students that only 2) use a simulation or work with 3) traditional hands-on laboratory methods. As a result, compared to traditional laboratory work, the simulation-laboratory-combination environment was particularly effective. It improved more effectively students' overall knowledge of DC circuits and facilitated the development of scientifically acceptable models of current flow and current division.

Introduction

Electricity is a fundamental driving force of our modern society. Unfortunately gaining understanding on electricity seems to be very challenging and difficult for students in various school levels. Numbers of studies conducted worldwide indicate that students still have many difficulties and misunderstandings after systematic instruction (Fredette & Lockhead, 1980; Shipstone, 1984; McDermott & Shaffer, 1992; Duit & von Rhöneck, 1998). Most typical difficulties are inabilities to relate theoretical models of electricity to real circuits, incomplete understanding of basic concepts of electricity, and incapacity to reason about the behaviour of electrics (McDermott & Shaffer, 1992; Duit & von Rhöneck, 1998; Ronen & Eliahu, 2000). These difficulties and misconceptions seem to be very resistant to change (Shipstone, 1988). As Psillos (1998) argues, the emerging picture worldwide is not promising given that an adequate knowledge of electricity has rarely been acquired by students by the end of secondary education.

There have been several attempts to overcome the difficulties in electricity learning. Traditional electricity teaching using textual learning material, concrete application tasks or hands-on laboratory work has been quite ineffective. After series of instruction learners have been still found to hold many misconceptions about electricity. However, text materials and laboratory exercises can have also some benefits. Text particularly developed for facilitating conceptual change has found to be effective for correcting some of the students' misconceptions and improving their conceptual understanding on simple DC circuits (Wang & Andre, 1991; Carlsen & Andre, 1992). The use of application questions and tasks has reported to be partially useful for developing understanding of electricity concepts (Wang & Andre, 1991). The effects were significant for males and students with moderate interest, but not always for females and students with high and low interest. Research also indicates that laboratory-based hands-on activities can offer special benefits for understanding of concepts and correcting misconceptions (McDermott & Shaffer, 1992). However, some of the misconceptions are so strong and resistant that even direct experience with the real phenomena may not always be effective for changing students' opinions (Ronen & Eliahu, 2000). As a one alternative, there have also been attempts to replace hands-on laboratory work with electricity simulations. Results of these studies provide rather inconsistent picture about thee effectiveness of simulations compared to other methods (e.g. laboratory exercises). In some studies no statistical differences have been found (although in more detailed analysis simulation was beneficial for mental model development; Carlsen & Andre, 1992; Chambers et al., 1994) whereas in others results speak in favour of simulations (Ronen & Eliahu, 2000).

This study aims to provide new methods for helping students to better understand electricity and acquire correct scientific model about simple DC circuits. It examines if a simulation or combination of a simulation and laboratory work can improve elementary school students' understanding of simple DC circuits. The study is part of the three year R&D project, 'CELEBRATE' (Context eLearning with broadband technologies), funded by European Commission. Project aims are to create and share critical mass of online digital learning materials, and test their usefulness and effectiveness in everyday school practice across Europe. As we believe that one of the reason for the moderate success of previous attempts to overcome the difficulties of electricity learning have been due to rather one-sided teaching methods, leaning only on one method at the time, we have designed a learning environment that tries to combine the strengths of traditional laboratory exercise and simulation working with tasks that explicitly address common difficulties in learning electricity. Our hypothesis is that using a simulation can help students to better understand the theoretical principles of electricity by revealing the behaviour of DC circuit and visualizing the current flow in the circuit. Computer simulation can also provide immediate feedback to students about their actions and errors (McDermott, 1990; Ronen & Eliahu, 2000). After understanding the basics of electricity on a theoretical level (simulation) makes it easier for a student to transfer acquired knowledge into real circuits. By using both of these methods in parallel can help students to acquire more coherent picture of the topic. However, as working with simulation often resembles scientific discovery learning where students conduct various experiments and infer the underlying model, simulation work may be too overwhelming for some of the students (de Jong & van Joolingen, 1998). We have tried to avoid this by designing special assignment cards that structure student work and address the common difficulties and misconceptions found in various studies. In order to test our hypothesis, three learning environments, 1) laboratory exercise, 2) electricity simulation, and 3) simulation-laboratory-combination were created, and results of their effectiveness on developing students' understanding of simple DC circuits are reported in this paper.

Methods

The study

The study was conducted with 66 10-11 year old Finnish elementary school students. In the beginning of the study students were asked to fill in the pre-test electricity questionnaire and Raven's (1958) Standard Progressive Matrices (Sets A-E) test. In the pre-test students had to fill out four sections: 1) they had to evaluate in which circuit a bulb would be lit (understanding the concept of a closed circuit); 2) draw how electric current flows between a battery and bulb; 3) infer in which circuit a bulb is the dimmest; 4) and calculate the voltage of each bulb in different circuits (single bulb circuit, series circuit and parallel circuit) when the power source stays constant. Based on pre-test scores, students were matched into three different conditions.

1) In the LABORATORY GROUP (n = 24) students built real circuits with batteries, bulbs, wires and switches, and measured current with a multimeter.
2) In the SIMULATION GROUP (n = 20) students used an online simulation, the "Electricity Exploration Tool" (Figure 1), which allows them to build simple DC circuits with batteries, bulbs and wires on a diagram level. The simulation also allows students to observe the behavior with their circuits by running the model they have built and measure voltage with a multimeter.
3) In the MIXED GROUP (n = 22) students used the Electricity Exploration Tool and the real circuits both. In this group they were first asked to complete the assignment using the simulation and then, after succeeding with the simulation, repeat the assignment with the real circuits.

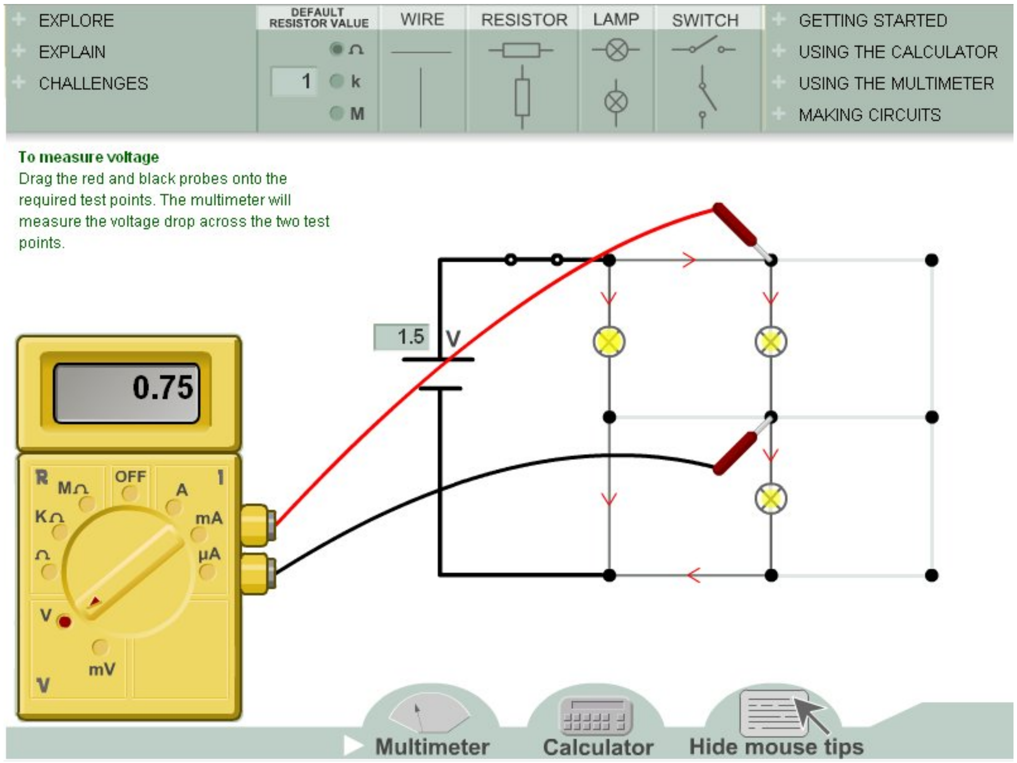

Figure 1. The Electricity Exploration Tool.

In each condition students were divided into two sub-groups (10-12 students in each sub-group). In these sub-groups students worked in pairs. The same teacher was teaching each group. Pairs in each condition received exactly same instruction, which was given in specially designed assignment cards. Assignments in these cards focused on basic electricity concepts, addressed students' common difficulties and misconceptions found at various studies, and structured student work. The contents of the assignments proceeded from a very simple DC circuit with one battery, wires and a bulb to the last more challenging tasks where they had to, for example, construct a circuit in which the brightness of four bulbs is A>B>C=D. The instruction then become more complex including simple closed circuit, two and more bulbs in series circuit, two and more bulbs in parallel circuit, two batteries in series and parallel connections, and problem solving tasks to construct circuits according to various requirements. All the time students were required to measure the voltages of the bulbs in different circuits and explicitly prompted to compare the characteristics of different types of circuits. Each card consisted of one assignment. Once students had completed the assignment they asked teacher to check their answer. Once the assignment was passed, student pair received next level assignment card. There were 12 assignments in total. Each group had two hours (one hour a day) to complete as many assignments as they could.

The post-test was administered day after training sessions. The post-test consisted of the same four sections as the pre-test, but it had four additional sections with more difficult questions. All the questions in test were designed to be equally fair for each condition. Although students worked in pairs, they completed all the tests individually.

Scoring

Students' answers in the pre-test and post-test electricity questionnaires were scored against model answer template. Raven's test was scored by using Raven's scoring key.

In order to gain deeper insight of students' conceptual change process in understanding the concept of current flow and distribution in a DC circuit, students' answers in four first sections (identical in pre-test and post-test) were reanalyzed by two independent raters (inter-rater reliability 0,92, disagreements were negotiated). First two sections of the pre-test and post-test measured students' understanding of the concept of current flow in a DC circuit. In the first section students had to evaluate in which circuit a bulb would be lit (e.g. only one wire leaving from a battery to a bulb or two wires from the same pole [short-circuit]), and in the second section they had to draw how electric current flows between a battery and bulb (one battery with wires leaving from + and – poles to a bulb). Based on students' answers to these two questions, their conceptions of DC circuits were classified into three:

1. Inconsistent model. In this most primitive category, students 'answers were inconsistent – the logic between different sub-questions didn't follow any particular principle. With some questions, answers followed the 'sink' principle (electricity can sink along a single wire connection from a power source to an electrical device), whereas in others, students' answers indicated the clashing current principle (below) or were somehow inconsistent.
2. Clashing current model. In this category, students reasoning followed consistently the clashing current principle. In this model learner believes that positive electricity flows from a power source's positive terminal, and negative electricity from negative terminal. Then the opposing currents meet at the electrical device where they clash. This clashing causes the device to work.
3. Correct circular model. Current flow is unidirectional and continuous. The scientifically accepted model of DC circuit.

Questions in third and fourth section measured students' understanding of current division in a DC circuit. In the third section students had to tick from three alternative circuits the one with the dimmest bulb and in the fourth section they had to calculate the voltage of each bulb in 1) one and 2) two bulb series circuit, and in 3) two bulb parallel circuit. Student answers were classified into two categories:

1. Correct solution. All answers are correct, which requires understanding of current distribution in both series and parallel circuit.
2. Wrong solution. One or more answers are incorrect.

Such tight criteria were chosen in order to avoid the effect of guessing.

Results

Overall development

As students were matched into different conditions, there was no difference between the groups in total pre-test scores or in any of the four section scores (ANOVA $p > .05$). Despite the matching procedure, in order to minimize the effect of pre-electricity-test and Raven scores, ANCOVA was used to compare student post-test scores in different condition. For the total post-test scores, ANCOVA showed statistically significant effect of treatment, $F(2, 66) = 5{,}090$, $p = .009$. In the post-test, the Laboratory group (LG) scored 9,98 (3,83), Simulation group (SG) 12,90 (4,03), and Mixed group (MG) 12,63 (3,87). Bonferroni's post-hoc test revealed that the difference in the post-test means was statistically significant between MG and LG ($p = .013$) in favor of the former, and almost significant between SG and LG ($p = .053$; LSD test $p = .018$). Between the groups that used the simulation (SG & MG) there was no difference ($p = 1.00$). The same tendency occurred between conditions in every post-test sub-section.

When investigating the effects of training on students' with low and high pre-test scores, results in Figure 2 show that students with high prior knowledge outperformed students with low prior knowledge in a post-test scores in every condition. ANCOVA revealed that there was statistically significant difference between conditions among low prior knowledge students ($F(2, 30) = 4{,}564$, $p = .020$): MG significantly outperformed LG (Bonferroni $p = .024$), and SG nearly significantly outperformed LG (Bonferroni $p = .110$; LSD $p = .037$). Between the simulation groups there was no difference. Although the same tendency between conditions was also found among high prior knowledge students, the difference between the groups was not statistically significant, $F(2, 36) = 2{,}225$, $p = .125$.

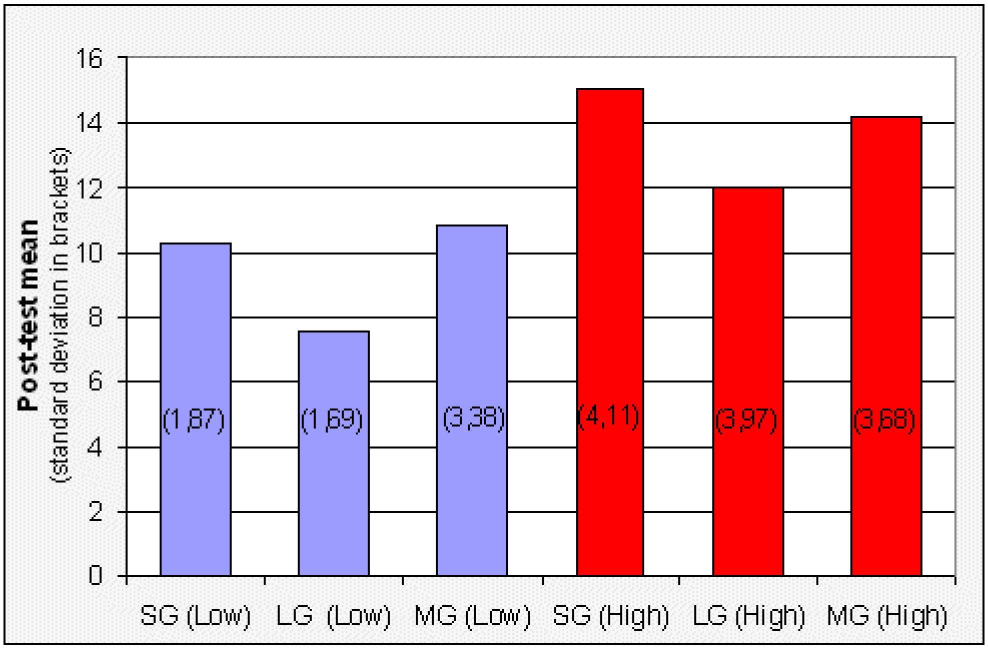

Figure 2. Post-test scores of students with low and high prior knowledge in different conditions.

ANCOVA of post-test scores of low and high educative ability (Raven test scores; MD = 43,5) students revealed same trend as comparison among low and high prior knowledge students: Among students with high educative ability simulation users (SG M = 13,59, SD = 3,87; MG M = 13,82, SD = 3,97) succeeded slightly better than LG (M = 12,10, SD = 4,22), but the difference between conditions was not significant, F (2, 33) = 1,291, p = .290. Among students with low educative ability, the simulation users (SG M = 12,06, SD = 4,30; MG M = 11,45, SD = 3,55) outperformed significantly LG (M = 8,19, SD = 2,40), F (2,33) = 4,495, p = .020. Difference between SG and LG was statistically significant (Bonferroni p = .045) and between MG and LG almost significant (Bonferroni p = .055; LSD p = .018). Between simulation groups there was no difference.

Conceptual change in understanding the current flow in a DC circuit

Table 1 presents the frequencies of pre-test and post-test response categories in understanding the current flow in a DC circuit by the students' working in different conditions. In the pre-test approximately half of the student responses are scientifically correct (circular model) in each condition. In the post-test, all the groups advance. Although the proportional amount of correct responses is slightly higher among Simulation (SG) and Mixed (MG) groups compared to Laboratory group (LG), the difference between the groups was not statistically significant in pre-test or post-test, p > .05 (χ^2). However, the Wilcoxon Signed Ranks test showed, that the pre-test-post-test change was significant in the SG (Z = 2,111, p = .035) and MG (Z = 2,443, p = .015), but not in LG (Z = 1,814, p = .070).

Table1. Pre-test and post-test response categories in understanding the current flow in a DC circuit

	Laboratory group (n=24)		Simulation group (n=20)		Mixed group (n=22)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
1. Circular (correct) model	10	16	10	17	9	18
2. Clashing model	9	5	9	2	9	3
3. Inconsistent model	5	3	1	1	4	1

In order to see in more detail how students with different preconception levels advanced from pre-test to post-test in different conditions, inconsistent and clashing models were merged as incorrect responses. As can be seen from table 2, in LG and SG seven students and in MG ten students improved from incorrect pre-test answer to correct post-test answer. In LG there are more students who don't develop between the tests than in SG and MG. In LG and MG, there is one student whose answer drops from correct to incorrect. The McNemar test confirms the results obtained from the Wilcoxon Signed Ranks test: pre-test-post-test development is significant in SG (p = .016) and MG (p = .012), but not in LG (p = .070).

Table2. Pre-post-test change in understanding closed circuit

	Pre-test	Post-test	
		Incorrect	Correct
Laboratory group	Incorrect	7	7
	Correct	1	9
Simulation group	Incorrect	3	7
	Correct	0	10
Mixed group	Incorrect	3	10
	Correct	1	8

Conceptual change in understanding the division of current in a DC circuit

Table 3 presents the frequencies of the students' correct and incorrect pre-test and post-test responses in understanding the concept of current sharing in a DC circuit. As can be seen from the table, more students in groups that used simulation advanced from incorrect solution to correct solution, but the overall development in all groups was small. The Chi-square test showed no difference between the groups in pre-test and post-test (p > .05). According to the McNemar test only MG's pre-test-post-test development was statistically significant (p = .016).

Table 3. Pre-test and post-test response categories in understanding the division of current in a DC circuit

	Laboratory group (n=24)		Simulation group (n=20)		Mixed group (n=22)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
1. Correct solution	3	5	3	7	2	9
2. Incorrect solution	21	19	17	13	20	13

Conclusions

Although electricity is a common science topic and it is relevant to everyday life, majority of people at all ages has many misconceptions and difficulties in understanding basic concepts and principles related to electricity. Despite various attempts to overcome these problems, none of the previous methods has proven to be particularly effective. We believe that one reason for the moderate success of previous attempts has been the use of only one method at the time. The other explanation may be that teaching of electricity is starting too late. Electricity teaching is rare for elementary school students, and all the previous studies have concentrated on 15 year olds or older. In this paper it was examined whether a simulation-laboratory-combination with structuring assignments could enhance elementary school students learning of electricity and help them to overcome known difficulties in the subject matter.

According to the results of this study, a simulation was able to improve students' learning outcomes compared to laboratory work. Simulation-laboratory-combination seemed to be even more effective, since especially the overall performance of the simulation-laboratory-combination group was statistically significantly better than Laboratory group's. Content analysis showed that the simulation helped the students to acquire scientifically accepted model of current flow, but only the simulation-laboratory group's comprehension of current division in a DC circuit advanced statistically significantly from the pre-test to the post-test. One explanation for the success of the simulation-laboratory-combination could be that simulation helps students to understand the theoretical principles of electricity by revealing the behaviour of DC circuit and visualizing the current flow in the circuit. After understanding the basics of electricity on a theoretical level makes it easier for a student to transfer acquired knowledge into the laboratory exercises with real circuits, and as a consequence acquire more coherent and holistic comprehension of the topic. Thus the combination of laboratory and simulation work can bridge the gap between theory and reality.

Examination of ability groups revealed that the use of simulation can be particularly beneficial for students with lower prior knowledge and educative ability. This result is little surprising since in previous studies simulations are considered as rather challenging environments for learners (de Jong & van Joolingen, 1998). One explanation for the observed result may be that assignments cards may have helped weaker students by structuring simulation environment and guiding students to focus on relevant issues. Findings of Veenman and Elshout (1995) on structuredness of learning environments support this explanation. It seems that the success of high ability students is not so dependent on learning environments because they seem to cope with every studied learning condition and they systematically outperform lower ability and lower prior knowledge students.

Results of this research provide encouraging evidence for using simulation in combination with hands-on laboratory work and structured assignments for electricity learning. Despite the obtained positive results, more supporting evidence and further development of learning environments is still needed in electricity education. For example, the concept of current division seems to be especially difficult for elementary school students to understand and its clarification thus requires more attention.

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