Electric Circuits in The Heureka Project: Multiple Representations

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Abstract

The main goal of teaching physics in The Heureka Project is developing the scientific ability of students in all levels of schools. We have more than twenty years of experience with teaching using different active methods of learning. This paper describes one of them – a method of building the concept of electric circuits and its different representations in students' minds. This method is used by teachers in lower secondary schools (ages 12 to 13 years), namely teachers who are involved in The Heureka Project. This paper shows the gradual process which helps students to really understand this concept and gives them the ability to solve different problems concerning electric circuits. Peer to peer interaction forms an integral part of this approach. Students discuss, explain problems to their classmates, and teach each other. Our method uses different representations of an electric circuit and the description of its function. In this paper we show several concrete examples of the tasks, which are solved during the learning process and also some students' solutions, to enable other teachers to use these activities in their schools.

Keywords: multiple representations, electric circuits, active learning

Electric circuits in The Heureka Project – multiple representations

Introduction

The development of students' scientific ability is one of the main goals of teaching/learning physics at schools all over the world. The term "scientific ability" is used for describing processes and methods that scientists use when constructing knowledge and when solving experimental problems.

Scientific ability is a very complex skill; the ability to represent information in multiple ways is one part of it.

The Rutgers Physics and Astronomy Education Research group [Etkina, Van Heuvelen, 2006] shows three sub-abilities which help to make this multiple representation strategy productive for reasoning and problem solving:

- The ability to correctly extract information from a representation;
- The ability to construct a new representation from another type of representation;
- The ability to evaluate the consistency of different representations and modify them when necessary.

Students can use the multiple representations in different topics - for example, motion diagrams and free-body diagrams in Mechanics, and ray diagrams in Optics.

"Simple electric circuits" is one of the traditional curriculum elements in physics at lower secondary schools. Students usually solve problems concerning light bulbs and their behaviour depending on the state of switches or sometimes they build real electric circuits; nevertheless, they have many misconceptions. Students have problems with understanding and correctly applying the concept of a complete circuit [Osborn, 1983].

In the study concerning the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) it was found that two thirds of high school students knew that a light bulb had two connections, but one-third believed that there was only one connection which was located at the bottom of the bulb. Students were able to translate easily from a realistic representation of a circuit to the corresponding schematic diagram. However, students had difficulty making the reverse translation [Engelhardt, 2004].

The results from different research studies show that students need more possibilities to work with real electric circuits. They need to understand multiple representations of the circuit to deeply understand its behaviour:

> Many students have no observational or experiential base that they can use as a foundation for constructing the formal concepts of introductory electricity. This deficiency in background can be a serious handicap when students attempt to relate electrical concepts to real circuits. In a survey of a large calculus-based physics class, we found that 60% of the students lacked previous experience with simple circuits. Only about 15% indicated that they had some familiarity with batteries and bulbs. [McDermott, 1992]

In the final part of this research report the authors suggest how this situation could be remedied:

> There is a need for instructional materials that foster the active mental participation of students in the learning process. The development of curriculum that fulfils this need should be guided by knowledge of what students know and can do, rather than by assumptions about what they should know and should be able to do. [McDermott, 1992]

In the Heureka project we have developed a five-step methodological sequence, which helps students to build the concept of electric circuits using multiple representations.

The Basic Information about the Methodological Sequence

This instructional approach is an example of the method used in teaching physics in The Heureka Project. It takes 5 consecutive lessons lasting r 45 minutes each. It is intended for pupils approximately 13 years old, who are being introduced to the topic of electric circuits for the first time at school. For the purpose of this article the results of 25 students were recorded in June 2012, but as mentioned before, these were “normal lessons” that have been used with students for many years already, and not specially adapted only for this research.

Aims:

- To elicit pupils’ current ideas about electric circuits, and to identify their possible misconceptions.
- To help them reconstruct their ideas which differ from the correct explanation.
- To teach pupils several different representations of an electric circuit (a real connection, a circuit diagram, a table describing the state of switches and bulbs).
- To teach pupils to solve three types of tasks concerning electric circuits.

This teaching-learning sequence has five steps:

- The first step: FINDING PRECONCEPTIONS
- The second step: CHECKING IDEAS and THEIR RECONSTRUCTION (if necessary)
- The third step: DISCOVERING PROPERTIES OF AN ELECTRIC CIRCUIT
- The fourth step: Determining Properties of Working Electric Circuits and Interpreting A Circuit Diagram
- The fifth step: SOLVING THREE TYPES OF TASKS WITH CIRCUITS

The topic Electricity is reintroduced two years later in the 8th class. Pupils in this class recognize the concepts of current, resistance and voltage, find Ohm’s law using water model of an electric circuit and calculate the total resistance of series and parallel resistors. They are also guided in developing more complex concepts, such as electric power and energy.

In this paper we concentrate only on the first part of the teaching of electricity, at the first ideas about the simple electric circuit. During the first lesson (on the 1^{st} – 3^{th} step of the methodological sequence) students work with a worksheet (see Appendix 1; only several tasks from the worksheet are included in this paper). During the second lesson, students investigate the 4^{th} step of the sequence. The three types of tasks with circuits (the 5^{th} step) are solved in the last three lessons.

The First Step: DETERMINING PRECONCEPTIONS

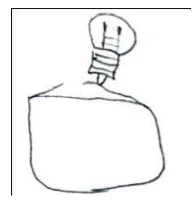
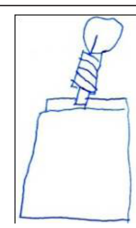
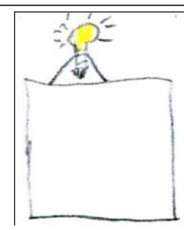
Worksheet Task 2: *Draw your idea of how to make the bulb light. (You have only the bulb and battery, nothing else).*

In this step students are not allowed to actually connect the elements to try to make the bulb shine. They only imagine how to do it and draw their ideas. (Note: We use the batteries with two longer terminals, see Figure 3.)

The ideas students drew on their worksheets could be divided into five groups - see Table 1.

Table 1

Answers for the Worksheet task 2

Group	Type of answers	Number of answers	%	Example
A	correct	9	36%	
B	the bulb touches only one pole of the battery	6	24%	
C	the bottom point of the bulb touches both poles of the battery	4	16%	
D	the lateral point of the bulb touches both poles of the battery	3	12%	
E	confused	3	12%	

The Second Step: CHECKING IDEAS and THEIR RECONSTRUCTION (if necessary)

Worksheet Task 3: *Try your idea. Was it correct? Write whether the bulb shines.*

Worksheet Task 4: *If the bulb doesn't light up, try to play with it and make it light. Then draw the arrangement of a battery and a bulb for which the bulb lighted.*

In the second step each pupil can check his previous idea. He can play with a bulb and a battery (without wires). He tries to make the bulb shine and evaluates whether his previous opinion was right or not. What is important is the fact that the correctness or incorrectness is determined by experiment, not by the teacher's authority.

Figure 1. Does it shine?

Almost all students whose ideas were not correct (students from the groups B, C, D) were successful now. They discovered the right solution. Only three pupils from group E had difficulties with this task.

The Third Step: DISCOVERING PROPERTIES OF AN ELECTRIC CIRCUIT

Worksheet Task 5: *Competition for pairs: Connect the bulb to the battery through as many things as possible at the same time so that it shines.*

Record your findings. We were able to make the bulb shine when connected to the battery through ....pieces at the same time.

In this step, pupils find the basic properties of the electric circuit. This activity is very popular with children. Pupils are competitive, so they like it very much. Usually they are able to make the bulb shine using 20 – 30 pieces at the same time.

Figure 2. Concentration during a competition

Figure 3. Non-traditional electric circuit

Worksheet Task 6. *Sketch how the experiment looked (using 4 – 5 pieces is enough)*

Students did not have problems with this task. Several students' solutions are shown below.

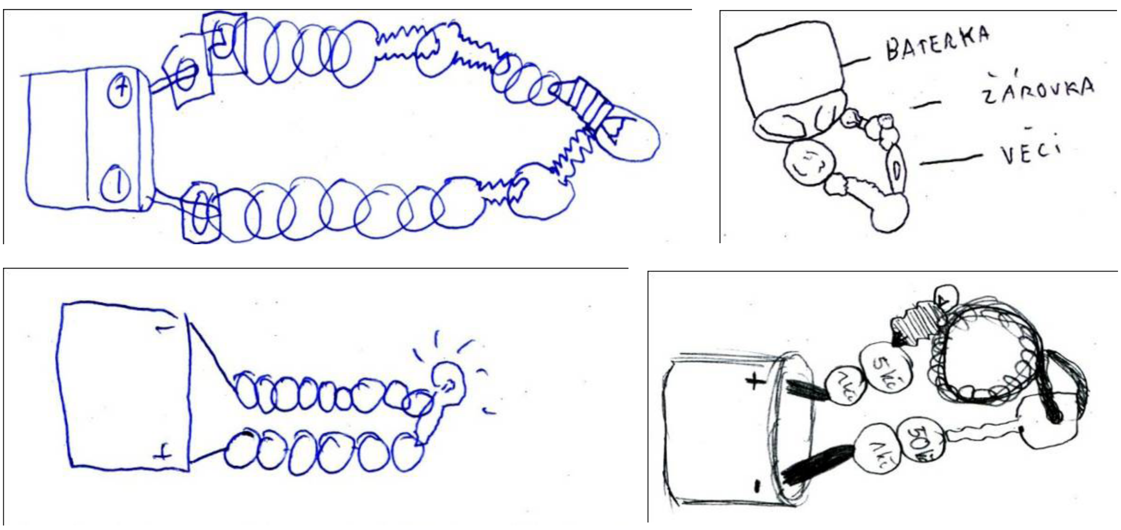


Figure 4. Several students' solutions of the non-traditional electric circuit

The Fourth Step: DETERMINING PROPERTIES OF WORKING ELECTRIC CIRCUITS and INTERPRETING A CIRCUIT DIAGRAM

At the beginning of the second lesson during a teacher - students' discussion, students determine necessary conditions for lighting the bulb at the competition in the last lesson. The teacher must not tell students those conditions; students are able to formulate them independently.

Necessary condition for lighting the bulb – students' answers:

- All things are conducting.
- All things are in contact.
- All things are connected in a complete loop. Each of two terminals of the bulb is connected to a different terminal of the battery through a continuous conducting path.
- The bulb and battery are in working order.

After this discussion the teacher shows the pupils circuit diagrams to represent circuits and also tables for describing the state of switches and bulbs. The brightness of individual bulbs is not important at this level.

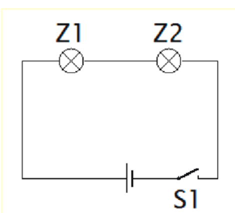
In the second part of this lesson pupils work in groups. They work with real bulbs, switches and batteries and build assigned circuits.

Students fill in the tables and then connect bulbs and switches to check their hypothesis. Students like these problems because they work, think, and discuss ideas together.

Example:

A circuit diagram of a series electric circuit and the table describing its behaviour.

(Z1 and Z2 means bulbs, S means switch, 0 means an open switch or a dark bulb, 1 means a closed switch or a shining bulb)



S1	Z1	Z2
0	0	0
1	1	1

Figure 5. An example of a schematic diagram of a series circuit and the table describing its behaviour.

As you can see in the photo of the blackboard (Figure 6), pupils are able to solve rather complicated problems very soon. In task number 4 there is a short connection – the behaviour of the bulb 2 is very surprising for students. The teacher has to explain it!

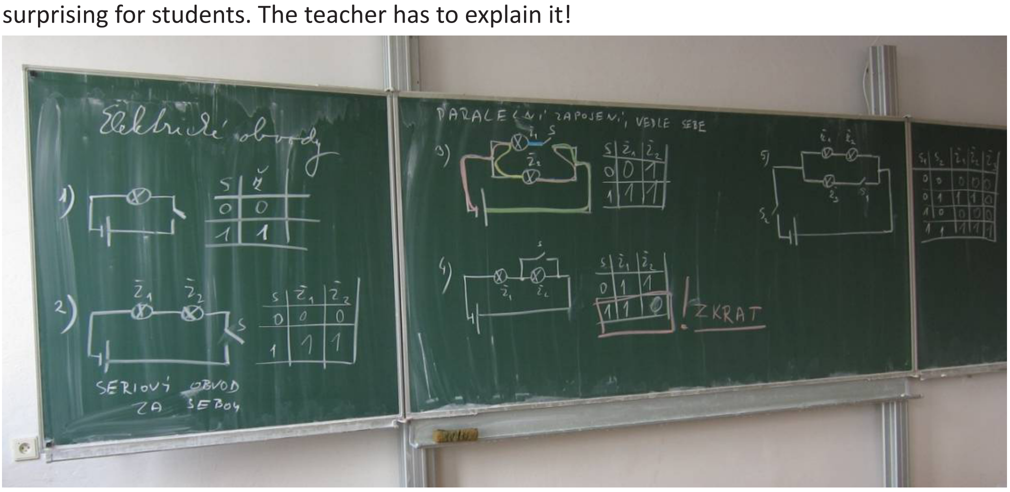


Figure 6. The first five tasks concerning simple electric circuits, their diagrams, and tables.

The Fifth Step: SOLVING THREE TYPES OF TASKS WITH CIRCUITS

- The first type:

  Start from the circuit diagram. Fill in the table and build the circuit.

- The second type:

  Start from the table (or the verbal description of the function of the circuit). Draw the circuit diagram and build the circuit.

- The third type:

  Start from the real circuit. Draw the circuit diagram and fill in the table.

During the third lesson students continue solving the first type of tasks with circuits. They work in groups of three or four; they work with real bulbs, switches, and batteries. Students start from the circuit diagram, draw the table and make the connection for more complicated circuits. They find the function of a two-way switch.

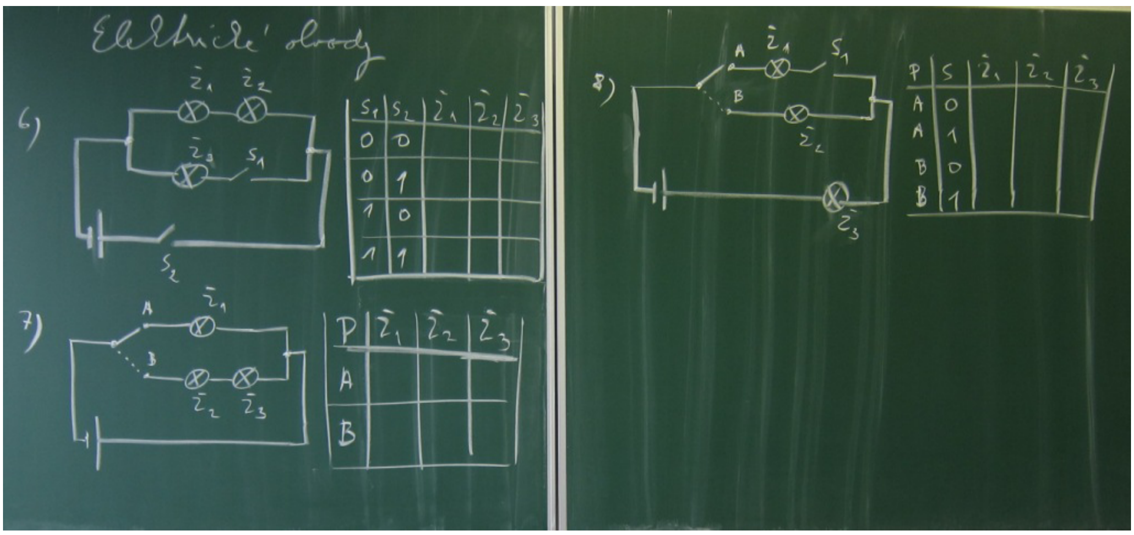


Figure 7. A more complicated task concerning simple electric circuits, its diagrams and tables.

Figures 8., *9.* Building electric circuits

Students are usually very active when "playing" with bulbs and batteries. They are able to help (and to teach) each other.

The fourth lesson is focused on the second type of tasks with circuits: Students start their work from the table (or the verbal description of a function of the circuit) and they draw the circuit diagram and build the circuit. This type of task is much more difficult for students. Sometimes they need help from other students or from a teacher. Two examples of this task are in Figure 10.

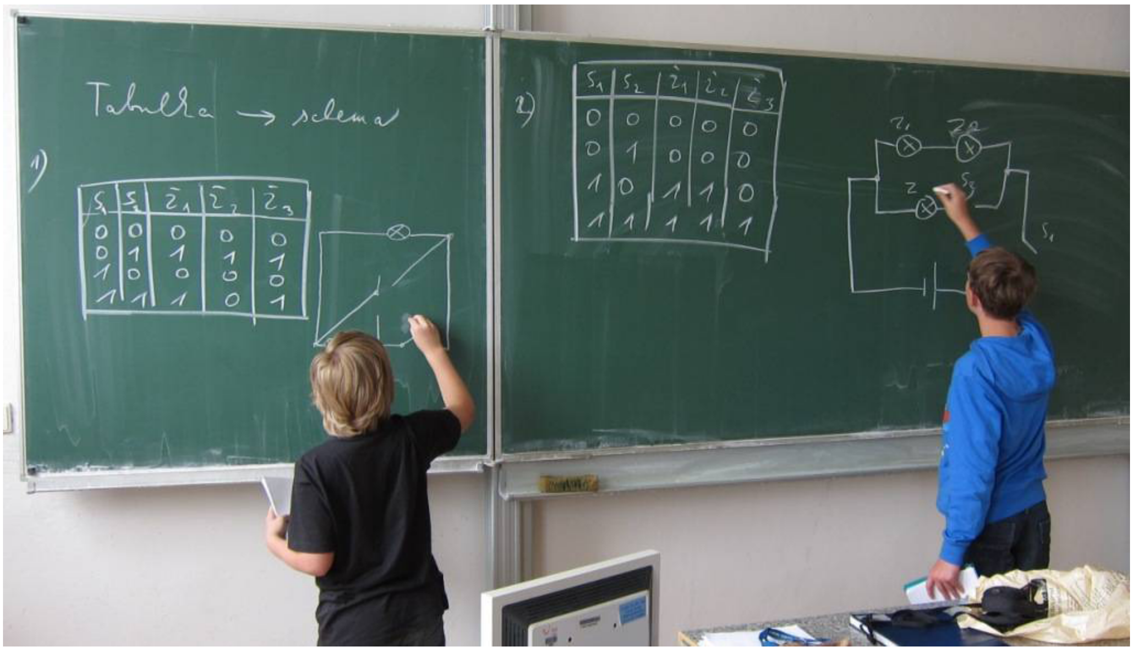


Figure 10. From the table to the circuit diagram

The fifth lesson of this methodological sequence is focused on the third type of tasks with circuits: One student from each group devises some circuit diagram and connects the real circuit which corresponds to his diagram. The others then examine this real circuit and have to draw the diagram and fill in the table. The author of the task checks their solutions. This problem is difficult both for the student who prepares the task and for the others who solve it. The discussion in a group is usually very intense.

Continuation of the Topic of Electricity

The five lessons described in previous paragraphs contain the basic knowledge concerning electric circuits which students (about 12 - 13 years old) should know. This topic is reintroduced s two years later. Older students recognize concepts of current, resistance and voltage and find Ohm's law using a water model of an electric circuit; moreover, they calculate the total resistance of series and parallel resistors. They are also guided in developing more complex concepts, such as electrical power and energy.

Conclusions

From my own long time experience I can say that the approach in which students themselves formulate hypotheses, find the properties of bulbs, and solve different problems helps them to deeply understand the concept of electric circuits.

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Appendix

Worksheet - electricity **Name.......................................**

1. Sketch what the bulb and battery look like.
2. Draw your idea of how to make the bulb light (you have only the bulb and battery, nothing else).
3. Try your idea. Was it correct? Write whether the bulb shines.
4. If the bulb doesn't light up, try to play with it and make it light. Then draw the arrangement of a battery and a bulb for which the bulb lighted.
5. Competition for pairs: Connect the bulb to the battery through as many things as possible at the same time so that it shines.
6. Record your findings. We were able to make the bulb shine when connected to the battery through ....pieces at the same time.
7. Sketch how the experiment looked (using 4 – 5 pieces is enough)
8. Your picture probably wasn't neatly arranged; it would be difficult to print it to the text book. Try to draft a simpler way of illustration.