Physics: a black box?

L'udmila Onderová from PJ Šafárik University, Košice, Slovakia, introduces us to the use of black boxes in the physics classroom.

Figure 1. Materials required for the black box

Images courtesy of L'udmila Onderová

Figure 2. Construction of the black box

Figure 3. The finished black box

The idea behind using a black box in the classroom is for students to try to figure out its contents – prepared in advance by the teacher – without opening it. Once they have experimentally determined what is inside, the students can open the box to verify their hypothesis. An example of how to use black boxes to teach electric circuits, suitable for students aged 15-18, is described below. However, there are many possible uses for black boxes in the classroom, also for younger students and in other areas of physics[w1].

I've had good experiences using this method both in the classroom and in the education of future physics teachers. Many teachers don't seem to be familiar with it, yet it is actually very similar to problems you have to solve in real life. Besides, the experiment fosters the creativity of students, and black boxes are cheap and easy to build.

Building the black box

Materials

- A plastic pill tube (e.g. from effervescent vitamin C)
- A drill
- Two banana jacks (e.g. the plugs on the cables connecting the amplifier to the loudspeakers in a hi-fi sound system)
- Electronic components (e.g. resistors, capacitors, diodes, etc.) to fit inside the tube
- Flexible line wires

Procedure

- Drill a hole into each end of the tube.
- Push the banana jacks through the holes.
- Connect the electronic component(s) to the jacks using the wires (see Figure 2).
- Fit it all inside the tube, and close it.

A removable tube top and flexible wires make it easy to reveal the components and the circuit inside the black box. You should make sure that the connection of elements inside the box is simple and easy to detect for the students. The outside appearance of the box is up to you; I wrap the tubes with a sheet of black paper.

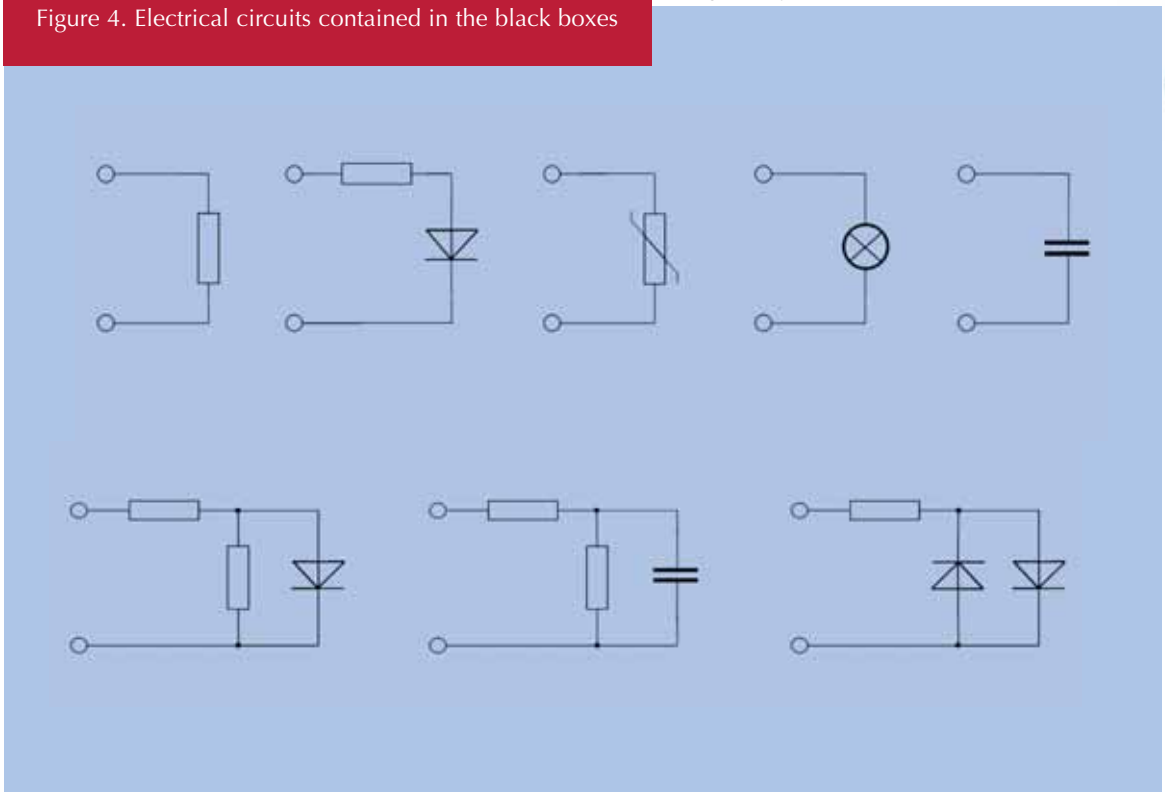
You can create black boxes of different complexity – some of them enclosing only one electronic component (resistor, capacitor, diode, coil, etc.), others containing several components connected to form simple circuits (see Figure 4).

Experiments with black boxes

Once students have been introduced to the basics of DC and AC electric circuits, they can start experimenting with black boxes to apply what they have learned to the solution of a practical problem. They are given materials (listed below) to be used for determin-

Figure 4. Electrical circuits contained in the black boxes

Image courtesy of L'udmila Onderová



ing the individual elements contained in a black box. They are informed in advance about all possible internal configurations of the boxes. In the first stage, each group of students receives five black boxes containing only one electronic element per box. In the next stage (not necessarily in the same lesson), they receive eight black boxes with either a simple or more complex configuration inside each one. Their task is to find out the contents using their experience and an algorithm they develop for analysis of the boxes.

Materials per group

- Five numbered black boxes containing individual electronic elements (resistor, coil, capacitor, diode, insulator)
- Eight numbered black boxes containing both simple and more complex circuits (see Figure 4)
- Leads
- An ampere-meter
- A voltmeter
- A source of DC and AC voltage
- A sketch of all possible internal configurations.

Procedure

1. Divide the students into groups of 2-3 students.
2. Hand out all materials.
3. Students have 30 minutes to measure the five simple boxes and determine their contents.
4. Each group reports their results.
5. Compare the results, and verify by opening the black boxes.
6. If the hypothesis was wrong, determine where the mistake comes from. In my experience, students have a success rate of about 80%. They usually have trouble distinguishing a coil from a resistor, as they are usually satisfied with finding that a box conducts electric current and don't analyse its value.
7. Try to set up an optimum algorithm to determine the elements in the box. This is what a possible algorithm could look like:
   a) Set up an electric circuit consisting of a black box, a voltage source, an ampere-meter and a voltmeter.
   b) Use a DC voltage source, connect the circuit, measure the current and the voltage, and write down the results.
   c) Change the polarity of the DC voltage source, measure the current and the voltage again, write down the results and compare them with the previous ones.
   d) Use an AC voltage source, measure the current and the voltage and compare the results with the two previous measurements.
   e) Propose a hypothesis about the structure of the black box.
   f) Verify the hypothesis by additional measurements.
   g) Determine the contents of the black box.
8. Next, students have 40 minutes to determine the contents of the eight simple and complex boxes.
9. Repeat the evaluation as before. In my experience, students find this task more difficult, and not all groups are able to determine the contents of all boxes in the given time. The success rate is also lower, at about 70%. This is still a very good result, though, and would probably not be achieved if individual students were trying to solve the task, rather than groups.

In the second test, students tend to have problems not with determining simple elements, but with determining more complex circuits and distinguishing between a resistor, a thermistor and a bulb. They have to apply their theoretical knowledge and need to realise that it is necessary to change the voltage and, eventually, to draw a diagram to be able to determine the elements in the boxes correctly.

What value do students get from these experiments?

Manipulating black boxes is an attractive task for students to test their knowledge and enjoy their success. Some even try to find further opportunities to use this method in physics teaching themselves. Most importantly, students learn to use a systematic method of investigation. The black box experiment encourages students to ask and answer their own questions, express their predictions, test their hypotheses and communicate the results to their peers. Such an active method also helps to better understand the nature of science. In addition, this is also a good way to solve problems in real life, for example if you need to work out how a device (black box) works when you have lost the user manual.

A critical point in setting the task is the amount of information given on the possible structure of the box's contents. The teacher needs to ensure that the students have sufficient previous knowledge and to give clear instructions on how to proceed. Fewer instructions provoke more creative thinking, but if not enough information is provided, students may feel overburdened by the task and lose interest.

REVIEW

This is an interesting activity to be performed with secondary-school students. It is useful to practise a range of concepts in physics in a didactic way.

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Web references

w1 – For further examples of using black boxes in physics teaching, see:

The optical black box on the Science Olympics website:
www.physics.uwo.ca/science_

olympics/events/grades_9_to_10/optical_black_box.html

The black box mystery on the Science Olympics website: www.physics.uwo.ca/science_olympics/events/grades_9_to_10/black_box_mystery.html

Two black box experiments (IphO 2004 experimental question problem and IphO 2002 experimental question 2 problem) on the International Physics Olympiads website www.jyu.fi/ipho

'Archimedes: A Black Box Mechanics Laboratory' on the website of Colgate University, USA: http://departments.colgate.edu/physics/research/PhysicsEd/labs.htm

Resources

For further examples of using investigative methods in the science classroom, see:

Tifi A, Natale N, Lombardi A (2006) Scientists at play: teaching science process skills. *Science in School* **1**: 37-40. www.scienceinschool.org/2006/issue1/play

Tifi A, Natale N, Lombardi A (2006) Scientists at play: contraptions for developing science process skills. *Science in School* **2**: 20-23. www.scienceinschool.org/2006/issue2/play

Further reading on the use of black boxes in the classroom:

Amato JC, Williams RE, Helm H (1995) A "black box" moment of inertia apparatus. *American Journal of Physics* **63**: 891-894

Barney DM (1955) A "black box" laboratory assignment. *American Journal of Physics* **23**: 546

Burling RL (1957) Black boxes in the instructional laboratory. *American Journal of Physics* **25**: 492

Singh VA, Khaperde RB (2005) The mechanical black box: a challenge from the 35th International Physics Olympiad. *Resonance*, **10(4):** 75-82. www.ias.ac.in/resonance/Apr2005/pdf/Apr2005Classroom2.pdf

Terry C (1995) Black-box electrical circuits. *Physics Teacher* **33**: 386-387

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