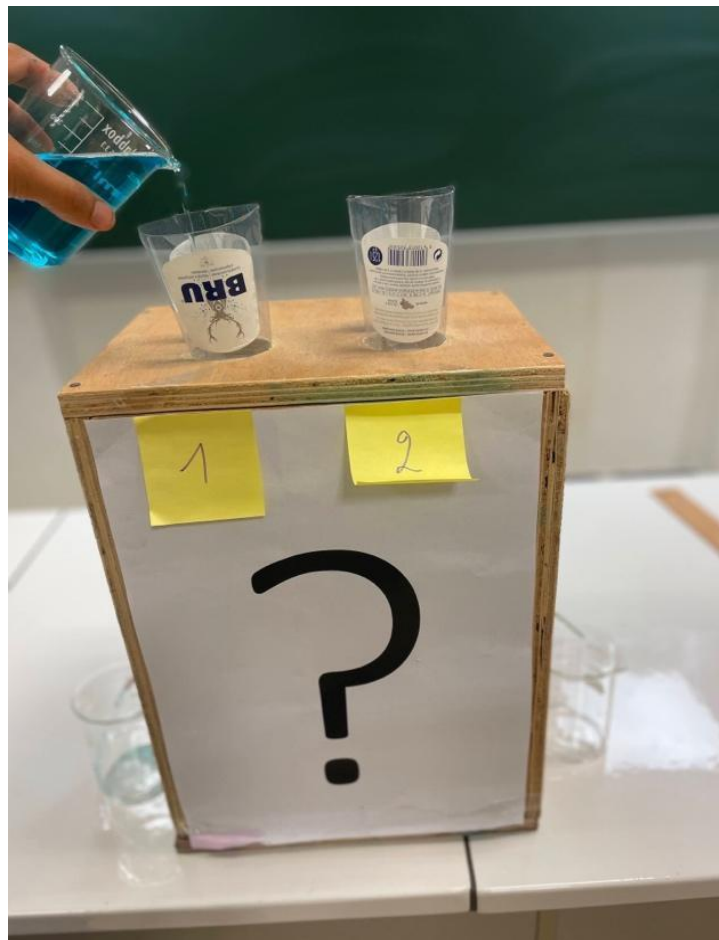


BLACK BOX: WATER-MAKING MACHINE

*STUDENTS COLLABORATIVELY PROPOSE MODELS TO EXPLAIN THE
BEHAVIOUR AND DESIGN OF A BLACK-BOX DEVICE*

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SUITABLE FOR AGE(S)

12 - 18 years

SUBJECT(S)

Chemistry

KEY FOCUSCollaboration
Proposing models**INTRODUCTION**

In school science, the focus is often on scientific results and established theories, while less emphasis is placed on how science works—the nature of science (NOS). To address this gap, this task introduces learners to the core processes of scientific inquiry through an engaging “black box” experiment called the water-making machine.

Learners are challenged to find patterns, formulate models to explain those patterns, and discuss and compare those models. They are prompted to reflect on how scientific knowledge is constructed and how certainty in science is built not through definitive answers but through iterative model refinement and experimental testing.

This task is based on a black-box activity designed by Lederman ('the water-making machine'), which helps students understand how models and theories are created in science and how they relate to patterns. Learners try to understand how the water-making machine (a black box) works. They look for patterns using the machine and create models to explain these patterns. These models are then compared and discussed. How confident are they about their model? How can they become more certain of it? After the discussion, they relate this to real scientific work.

Differentiating between patterns and models is a vital skill for scientists. In daily school practice, the distinction between both is not emphasised, leading to confusion between the concepts. It must be clear that patterns are not debated if they are derived from well-conducted experiments. However, finding the correct model is at the core of scientific debate. Often, special experiments must be designed to differentiate between models, as is also done during the task. Within this context, it is noteworthy that there is still ongoing discussion about how to accurately explain or model the siphon phenomenon (Richert, 2012; Wikipedia, 2023). For advanced learners, this discussion can be used to illustrate how real scientists have similar discussions as they did during their activity.

TASK DESCRIPTION

In this task, students examine how a black box labelled a water-making machine operates. They pour water into funnels connected to the box and observe the output, looking for patterns in the behaviour. From these observations, they formulate models (hypotheses) about what might be inside the box. Students

- Observe the black box's behaviour
- Identify patterns in the outputs
- Develop models that explain these patterns
- Discuss and compare different models as a class

- Reflect on how scientists develop and improve knowledge through experimentation and discussion.

No prior scientific knowledge is needed, though familiarity with the siphon principle may emerge and can be introduced during the lesson if needed. [Inside the black box, there is a hidden water reservoir that can be emptied by a siphon.

TASK PREPARATION

It is important that the teacher introduce or explain the siphon mechanism using relatable real-life examples (for instance, emptying the fuel reservoir of a car or the siphon in a toilet flushing system) or simple models.

Materials needed:

- One opaque box (cardboard or wooden)
- Two plastic bottles (500 ml each), tops removed to create funnels
- Straws or plastic tubing (for siphon mechanism)
- Tape and silicone sealant (for watertight seals)
- Water (optionally colored with food dye)
- Three 500 ml beakers
- Optional: Additional colored water for advanced tests
- Whiteboard or blackboard (for drawing models)
- Markers or chalk
- Paper and pencils (for student sketches)
- Timer (to track water delay if needed)

TASK IMPLEMENTATION

Constructing a water-making machine:



For this activity, a black-box water-making machine is constructed (see pictures above). You need a box (made of wood or cardboard), two empty plastic bottles, some straws or small tubes, tape, silicone, and three 500 ml beakers. Cut the top part of the plastic bottles to create a funnel. Drill a hole in the caps and connect the straws as shown in the pictures above. Use silicone to make the funnels watertight. Attach the bottom part of one bottle to the inside of the box and create a siphon using one of the straws. Fill this bottle with water. We added some colourant to the water to improve visibility, but this is optional. Ensure the bottle reservoir is only half-filled, allowing the siphon sufficient time to start working.

Step 1: Presenting the black-box phenomenon and trying to find patterns (10 min.)

The black box is presented to the learners. The first objective is to discover what is inside. Therefore, a fixed amount of water (200 or 300 ml) is poured into funnel 1 and later into funnel 2. Let the learners observe carefully and describe their observations (without making assumptions about what is inside the black box). If necessary, assist the learners in making detailed observations. How much water flows out of the machine? How long does it take for the water to flow out?

Step 2: Constructing a model/hypothesis (10 min.)

Let the learners, in cooperation with their neighbour, draw what they think is inside the black box. Emphasise that they are creating a model — a simplified representation of reality. The most important condition for a good model is that it can easily explain the observed patterns from part 1. Allow the groups 5 to 10 minutes to draw their models. Guide this process and identify which groups have interesting models. When each group has finished, let the learners draw their models on the blackboard. Have them present their models to the class.

Step 3: Finding the best model/hypothesis (10-20 min.)

Make the learners aware that their models are still hypotheses. As long as we are uncertain about a model, or if a model is not accepted by the majority of learners, it remains hypothetical. Guide a discussion about the different models on the blackboard. Which model is the best? How do they know that? Can we think of an experiment that could prove or falsify one of the models? For instance, learners often suggest there was water inside the black box before the water was poured in. To confirm this, a new beaker of water is poured into funnel 2. If no water comes out this time, it provides extra evidence that the machine is not producing water by itself. But what will happen if another amount of water is poured into funnel 2? Will more water come out than was poured in? Will the amount of water be greater than the amount added? Sometimes learners suggest pouring water of a different colour so they can better see which type of water was inside. The discussion continues until the majority of the group agrees that one of the models on the blackboard is the better one and explains all (or most of) the observations. However, sometimes two good models explain the observations, and the group remains divided. This is not a problem because such disagreements happen frequently in science.

Step 4: Linking the activity to the nature of science (10 min.)

Before revealing what is inside the black box, discuss how this activity parallels what real scientists do and how science functions. Scientists conduct experiments to identify patterns and develop hypothetical models. To become more confident in their models, they perform additional experiments that may either confirm or falsify their theories. But are they truly certain in the end? Are scientists able to open the box and genuinely observe how things are working? For advanced learners, it is interesting to note that, despite knowing the siphon principle, there is still some debate about how to accurately explain the siphon phenomenon (Richert, 2012; Wikipedia, 2023). This highlights the nature of science. As long as there is debate, science is active.

KEY LEARNINGS

This task has been tested with pre-service and in-service teachers. The challenge of finding a good model is highly motivating, and engaging discussions often develop as participants attempt to identify the best model. It is important to note that the teacher may not always provide the correct answer themselves. The teacher's only responsibility is to clearly distinguish between models and patterns and to help learners differentiate between them. In our experience, the siphon principle is often suggested by learners themselves, although sometimes the teacher must offer hints ('How can you get fuel out of a car tank?' 'How is a toilet flushed?'). Even if learners do not arrive at the correct model based on a siphon, the activity remains an excellent example of how science progresses. Furthermore, real scientists often do not find a definitive model.

CONCLUSION

This task emphasises important cross-cutting concepts, such as models, patterns, and hypotheses (Council, 2012). However, it is crucial that these concepts are also integrated into normal lessons. Only through this approach will learners develop a deep understanding of these concepts and the nature of science. Learners are motivated to investigate daily-life phenomena more thoroughly and to critically evaluate the models they use to explain these phenomena. Learners explore the black-box system called 'water-making machine'. They are guided to identify the patterns within the black box and to develop their own models of its internal workings. The core of this task lies in discussing various models. Questions such as 'Which model is the best?' and 'How can we be certain of this?' serve as guiding questions. Learners discover that science does not offer absolute certainty and that it is an ongoing pursuit of improved models. However, at times, some models can be sufficiently convincing to most scientists.

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