Science in School
The European journal for science teachers

ISSUE 59 – September 2022 **Topics** General science | Science and society

The mystery box challenge: explore the nature of science

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Thinking outside the box: Explore the nature of science by building LEGO mystery boxes and challenging your students to solve the puzzle.

How do we make informed decisions based on scientific evidence? Learning about the nature of science can help us with that challenge. The nature of science describes the values and underlying assumptions that are intrinsic to scientific knowledge. As such, understanding the nature of science is considered to be the core of scientific literacy.[1]

Research shows that different aspects of the nature of science are important for high-school students and should be taught explicitly.[2,3]

This activity teaches students the following:

- scientific explorations are guided by scientific theories;
- science is empirical and inferential;
- science is creative;
- science is tentative;
- science is a social endeavour.

Mystery-box activities are a powerful educational tool for teaching nature-of-science concepts.[4, 5] Mystery boxes come in various shapes and sizes, from closed boxes with simple everyday objects to water-based mystery boxes with systems of water tanks. You can find out more about different mystery boxes on the S'Cool LAB website: https://scoollab.web.cern.ch/mystery-boxes.

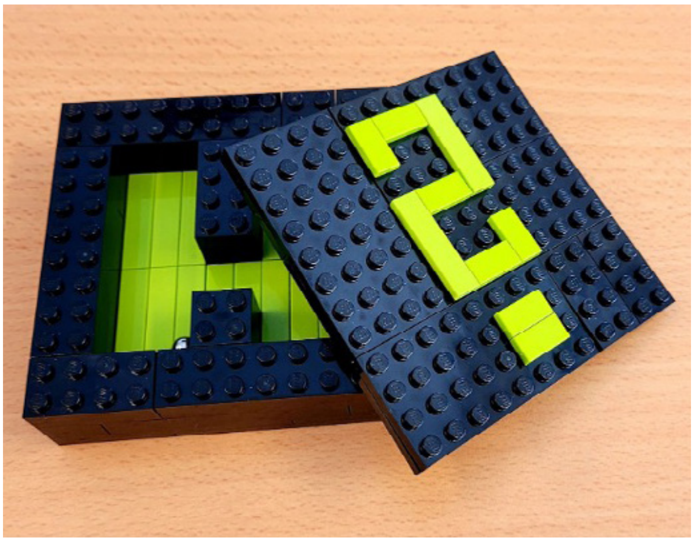

Figure 1: LEGO mystery box with a hidden internal structure
Image courtesy of the authors

Mystery boxes in the classroom

Activities with mystery boxes support students in experiencing different scientific methods and increase their understanding of the nature of science. These mystery-box activities can be used with students aged 14 and above and can be completed in around 90 minutes altogether, although teachers can decide to spend more time on the discussion.

Preparation: building a mystery box

The mystery boxes should be prepared before the activity. We use mystery boxes built with LEGO, as shown in figure 1. The internal structure is shown in figure 2. However, other mystery boxes can be used as well, for example, 3D-printed mystery boxes (https://scoollab.web.cern.ch/mystery-boxes).

The mystery box setup includes the following:

- **A base:** a base plate with an internal structure. Regular-sized LEGO can be used to build an internal structure on top of a base built with LEGO build plates.
- **A ball:** a solid ball is placed inside the structure of the base.
- **Lid:** LEGO build plates seal the box, so that the structure and the ball cannot be observed directly.

Figure 2: Inner structure of the LEGO mystery box; grey circle represents the ball
Image courtesy of the authors

The mystery boxes could also be built by a colleague and not the teacher directly. This reduces bias and enhances the experience of scientific exploration.

IMPORTANT NOTE: While it is tempting, **NEVER** open the mystery box, as that is not how science works. If students cannot resist the temptation, glue the box together (that's what we did).

Activity 1: Discuss theoretical models

At the beginning of the activity, the students are split into groups of 3–4. The teacher introduces the mystery-box activity to the students by explaining how the observation will take place.

Materials

Each group of 3–4 students receives

- Worksheet 1, showing the theoretical models (also shown in figure 3)
- mini whiteboards and markers

Procedure

1. Examine the theoretical models shown in Worksheet 1.
2. Devise experiments to test each theoretical model.
3. Discuss the outcomes of the proposed experiments; for example, if the second model is correct, what will be the outcome of the proposed experiment?
4. Discuss the limitations of the proposed experiments; for example, the fourth model in figure 3 contains an empty square in the corner, which cannot be observed using the ball.

Discussion

Scientific research is most often guided by theoretical models. In particular, modern research investigations rarely begin with a neutral observation of a phenomenon. For example, the theoretical prediction of the Higgs boson in 1964 guided the development of experiments that discovered the Higgs boson in 2012 – 48 years later! However, in the past, scientific research often stemmed from direct observations.

Figure 3. Four theoretical models of the possible inner structure of a LEGO mystery box; grey circles represent the ball
Image courtesy of the authors

Activity 2: Infer a model from indirect observations

In this activity, students put their ideas from Activity 1 into practice and try to identify the structure of the mystery box.

Materials

Each group receives

- LEGO mystery box with a hidden inner structure and a marble inside
- mini whiteboards and markers

Procedure

1. Perform the experiments proposed in Activity 1. For example, examine the mystery box by turning the box around and listening to the ball as it rolls around inside, hitting the walls of the internal structure.
2. Discuss possible internal structures and differences between observations and the four theoretical models that were provided.
3. Infer a model of the inner structure based on observations and draw the model on a mini whiteboard.

Discussion

Observations of natural phenomena are the basis of scientific claims. Scientists may make direct observations with their senses or measuring instruments. Alternatively, indirect observations may be made. With indirect observations, we only observe the results of the phenomenon, for example, we only hear the ball hitting the walls of the mystery box but cannot see the walls directly. In the end, scientists interpret their observations based on the relevant theoretical models to infer a scientific claim.

- Direct observation plus inference: scientists observe what a newly discovered animal is eating. From their direct observations, they can infer what the entire species is eating.
- Indirect observation plus inference: palaeontologists use observations of dinosaurs' anatomy and their digestive tracts to infer what those specific dinosaurs ate.[6]

Extension activity

Exploration of the mystery boxes can be done in a more detailed way by using a strong neodymium magnet as a probe. In this case, the ball inside the mystery box should be made of steel for the magnet to have an effect. After using the magnet, the students can update the theoretical models based on their detailed observations.

Safety note

neodymium magnets are very strong, so they should be handled with care, to avoid injuries, and not be placed close to electronic equipment.

Activity 3: Create an experiment to test the model

After proposing a model that is consistent with the observations of the mystery box, further testing is needed to support it. One way to do this is to build a model mystery box and see if it behaves the same way as the original mystery box.

Materials

Each group receives

- a box of various LEGO pieces, including several build plates
- a marble

Procedure

1. Create a new box based on the model proposed after observations in Activity 2.
2. Test the new box in the same manner as the original mystery box to see whether the results are identical or whether there are differences.
3. Discuss possible differences between the proposed model and the original mystery box, and use the conclusions to propose a new model.
4. With this activity, students can also explore model limitations, such as the empty square of the fourth theoretical model in Activity 1. By weighing the mystery box, students could infer the total number of LEGO bricks in the box, and thus, explore the contents of the empty square.

Discussion

Scientific investigations are not merely a rational and systematic activity. Scientists often need to be creative. For example, experimental designs often call for creative solutions using the materials and technology available. Similarly, finding better scientific explanations often requires thinking outside the box.

The first ever picture of a black hole required a very creative solution. Since none of the telescopes on Earth were powerful enough to record a good picture of a black hole, eight telescopes around the world were turned towards the same spot.[7] Likewise, biological structures are complex systems that often cannot be directly observed or understood from the knowledge of their constituents alone, so biologists need to come up with creative solutions. For example, to study the role of a protein in an organism, they may inhibit it and observe the consequences.

Extension activity

Before this activity, students can be asked to write a scientific proposal for a grant to receive additional equipment, e.g., LEGO for building a test mystery box. The students would only receive additional equipment after they had described their findings and explained their predictions. Additionally, any extra equipment could have an assigned price that students need to consider with respect to their 'budget'. This step enables further discussion about how science is socially embedded.

Activity 4: Present the findings

After completing the mystery box exploration, the groups present their study to the rest of the class. Through peer review of the presentations, students reach a consensus on the internal structures of the mystery boxes.

Materials

Each group receives

- mini whiteboard and markers
- Worksheet 2

Procedure

1. Each group creates a scientific poster on the mini whiteboard that outlines their research process and their final proposed model for the internal structure of the LEGO mystery box. Guidelines on what to include in the poster and the presentations are shown on Worksheet 2. These guidelines are then also used for peer review in the next step.
2. Each group presents their research and findings in a short 2-minute presentation to the class with the support of their poster.
3. Students give anonymous feedback to other groups by using the peer-review form in Worksheet 2.
4. Together with the class, the students discuss the anonymous feedback and ways to improve their posters and presentation and to reach a consensus on the internal structure of the mystery box.

Figure 4. Students present their research findings to one another on posters. From S'Cool LAB Summer CAMP poster presentation

Discussion

Scientific discoveries are shared with the scientific community in the form of conferences and publications. For example, the discovery of the Higgs boson at CERN was presented both live and through a videoconference to scientists around the world on 4 July 2012, and the scientists published two scientific papers on their findings. When papers are submitted for publication, they are anonymously reviewed by several independent experts to verify the methods, results, and conclusions. Through this anonymous feedback, scientists also receive suggestions to improve their work. After publication, the results are scrutinized by other researchers in the field. As more and more evidence is collected, the scientific community can reach a consensus.

At the end of the project, you can use the provided nature-of-science overview table to discuss the different aspects of the nature of science.

Extension activities

The mystery boxes from different teams can also be different. If the groups are unaware that there are differences between the mystery boxes, the conference part of the activity can be even richer, as they will discuss how to find differences and similarities between their models.

Instead of (or in addition to) poster presentations, students could write research reports describing their findings. These papers can then be anonymously peer reviewed by classmates to mimic the real publishing process in science.

Summary

The activities presented in this article are designed to enable students to experience the theoretical, empirical, inferential, creative, tentative, and social aspects of the nature of science in a hands-on and exploratory approach. «

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Resources

- Find more information on mystery boxes and additional ideas for building or using mystery boxes.
- Try the mystery-tube activity from the Science Museum Group.
- Build mystery boxes based on liquid movement from the Exploratorium Teacher Institute.
- Explore how research projects are chosen for funding with this role-playing activity: McHugh M et al. (2021) What is it good for? Basic versus applied research. *Science in School* **55**.
- Try more activities to explore phenomena that we can't observe directly: Akhobadze K (2021) Exploring the universe: from very small to very large. *Science in School* **55**.
- Learn about the importance of good experimental design in clinical trials: Le Guillou I (2021) Clinical trials count on more than statistics. *Science in School* **52**