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What's inside the pink box? A nature of science activity for teachers and students

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Abstract

Although learning about Nature of Science (NOS) promotes a variety of important outcomes, teachers often lack suitable activities for younger students to effectively address NOS. In this article I elaborate on a NOS activity developed for a teacher professionalisation workshop. The activity is suited for younger students as well, where clear links are made between elements of the activity and how science works.

Keywords: nature of science, teacher professionalization, scientific inquiry

Do our students know how science works, why they should have faith in science and its outcomes? Do they have a clear sense of how scientific knowledge is established and what the role of scientific experiment plays in this? These, and related questions, are addressed when we teach Nature of Science (NOS), understood as *the basic values and beliefs that make up the scientific world view, how scientists go about their work, and the general culture of the scientific enterprise* [1].

Despite the fact that NOS includes important and valuable ideas and concepts [1, 2], there are not many classroom activities that deal explicitly with NOS [3, 4]. In this article I present a NOS activity used in a teacher professionalization workshop. The activity addresses various aspects of NOS that we want to teach students. It shows that it can be very easy to teach NOS and it offers many opportunities to help support students in understanding and doing science.

1. Nature of Science in the physics curriculum

Many problems and issues we face today, can be (partly) solved by science. The development of an effective vaccine within a year is a recent and clear example of such an issue. The discussion about the vaccine and the debate about the efficacy of facial mask are examples that show how science plays an important role in our daily lives and how our lives are affected by it.

To participate meaningfully in these modern social issues and form an informed opinion on these matters, one needs to have a basic conceptual knowledge of various science topics and develop an understanding of scientific practices including experimentation and argumentation. This general scientific awareness and understanding of science are often called *Scientific Literacy* [5]. Important components of Scientific Literacy are understandings of NOS. In the given example, one can ask if and why we should trust such a vaccine or wear facemasks. NOS understandings help us to provide an answer to these questions. According to Driver *et al* [6]: 'If science education is to contribute effectively to improved public understanding of science, it must develop students' understanding of the scientific enterprise itself, of the aims and purposes of the scientific work, and of the nature of the knowledge it produces.' For the interested reader who wants to know more about the whats and whys of NOS in physics education, I recommend the recently published book *Nature of Science in Science Instruction: Rationales and strategies* [1].

Despite the fact that NOS covers important and valuable lessons [1, 2], the curriculum describes various learning goals which need to be attained [7], and it is recognized that scientific literacy (in which NOS plays an important role) is becoming more and more important [8], there are not many classroom activities that deal explicitly with NOS [3, 4]. In many countries the national exam does not address NOS. As a result of the high-stakes national exam teachers focus on the physics content rather than spend time on teaching NOS explicitly [4]. If teachers are aware of (the importance of) NOS, they assume that by performing practical work their students will pick up on ideas of NOS automatically [9]. However, these often cookbook style activities have a counterproductive effect in developing students' understanding of science. Following a recipe resulting in a single answer to a research question gives a 'false' image of science and how science works [10, 11].

2. Teacher professionalization

The problem seems clear: not many teachers are aware of NOS and its importance, they do not have a clear understanding of how to teach NOS and they lack materials and/or time to do so. Rather than blaming teachers, this notion is meant as a clear statement of how things are. Acknowledging these issues provides directions for teacher professionalization workshops and activities. Teachers should experience first-hand how valuable and educational the activity is and understand that simple tweaks and additions to already existing lessons can truly transform these 'regular' lessons into NOS lessons. Furthermore, the materials should be simple, cheap and readily available at every school so that what is taught in the workshop today, can be applied by the participating teachers tomorrow.

As a researcher and (former) physics teacher, I developed and gave several teacher professionalization workshops related to practical work and teaching scientific inquiry at secondary school level. This activity is part of a workshop that focuses on a learning pathway for physics inquiry in secondary physics education [12]. The activity found its offspring in the idea that teaching scientific inquiry does not always mean that students ought to be engaged in practical work where valuable time is spent on gathering data. This 'hidden' idea is conveyed throughout the activity. Furthermore, the activity deserves its place in a workshop on teaching scientific inquiry as NOS understandings are pivotal for experimental science lessons: If students do not understand how data and evidence differ from each other, how scientific conclusions are reached, that scientific knowledge is consensus between experts and a product of intensive consultation and discussion between experts judging the evidence for the stated claim, then it is unlikely that they will try to produce scientifically convincing answers to the research question posed. That is to say, pay attention to methods and procedures to first gather reliable data and subsequently weigh various potential explanations for the produced phenomenon.

To keep a clear storyline, I will elaborate on how this usually takes place before going into details about what the main ideas are which ought to be conveyed. These ideas are usually discussed directly after a specific aspect of the activity.

3. The activity

Imagine you would join my workshop. Upon entry, you see a small box wrapped up in pink paper resting in the middle of a centrally placed table, see figure 1. You arrived early and start to wonder what the purpose of the box could be, considering that the topic of the workshop is *teaching inquiry to secondary school students*. Your discussion with your neighbour on the matter is interrupted when I, without further introduction, pose the question: 'What is inside the box? Any ideas? Could there be a car inside? Or an elephant?' You have reasonable ideas of what could be inside and dismiss the two given examples based on the size of the box. However, a clear and final answer cannot be given at the moment. This requires further inspection.

I continue: 'Now, think of a single experiment that you can carry out which helps you in determining what is inside. However, opening the box is not allowed!' Surely, you have ideas of small experiments that can be carried out and propose one. You are allowed to carry out your proposed experiment, see figure 2. You lift the box and shake it. However, this leads me to correct you as only a single experiment was to be carried out. Lifting the box provides information of its weight and shaking it provides information of what is inside (whether it solid, etc). After you carried out the experiment, you are asked to share your findings and tell what you now know more than before the experiment. Questions like: 'Do you now know what is inside? Do you have an idea? Are you sure?' are posed.

Especially after shaking the box, figure 3, some teachers have a clear idea of what is inside: 'LEGO!'. As one colleague claims: 'I surely know how Lego sounds!'. My response is that this could indeed be true, Lego could be inside but I am not sure myself since I did not make the box. There can still be reasonable doubt about the correctness of the claim: 'Does everyone agree the box contains Lego? What if you are not familiar with Lego? If you have never seen it, have no idea how it looks like or how it sounds?' In the ensuing discussion it is recognized that a person who has never encountered a box of Lego would doubt that there is Lego inside.

Figure 1. The NOS activity only requires a small box wrapped up in pink paper with something inside.

Figure 2. Teachers take turns in carrying out their proposed experiment.

Some more experiments are considered and carried out. After no new executable ideas are brought up, the topic of experiments that could potentially be done with more advanced equipment are discussed. You propose: 'One could use an MRI or CT scan.' My response then would be: 'But would you start using experiments with expensive instruments if you are not sure whether it is worth knowing what is inside? Are you willing to invest if you are not sure that it yields adequate information?'

Figure 3. A teacher carries out an experiment to obtain information of what is inside the box.

In the last part of the activity I ask whether you were engaged in *doing science* [13]. Not all teachers agree with you that you were engaged in doing science as you applied formulated hypotheses, did experiments, observed and so on. Some colleagues do not agree that this pink box is related to doing science. To make the link with 'real' science more explicit, I ask whether you could think of a real physics experiment that resembles this experiment. We consider the research question 'what constitutes matter?' and the related experiments carried out in the last century. There are similarities between wanting to know what is inside the box and what is inside an atom. The eagerness to know has made us build the biggest and most expensive physics experiment in the world.

After this activity I introduce myself, share my (educational) background and elaborate on what the purpose of the workshop is.

4. Ideas to convey

The first idea in the activity is that every inquiry starts with a research question [14]. This research question should be interesting enough for the researcher to endeavour the required effort in finding a scientifically convincing answer. That is why a pink box is placed so centrally at a table before teachers even trickle in the room. The unusual use of a pink box in a workshop on scientific inquiry successfully arouses curiosity among the participants. The message here is thus not to merely present an experiment to students, but create an incentive, provide a reason for them to really know the answer [15].

The second idea is that with asking a research question, potential answers are generated. In scientific terms, hypotheses are formulated. Based on the shape and size, many objects that could be inside are excluded. After each experiment, some hypotheses are discarded (based on the weight, sound and so on) and new hypotheses, often more precise, are formulated.

When the idea of Lego is introduced ('I hear Lego'), two issues are discussed. The first issue concerns the difference between observation and inference. 'Do we all agree that we hear Lego? and if not, can we call this an observation? If not, what is a correct term that we can use?' The difference between observation and inference is repeated later on in the workshop using Lederman's Tricky Tracks [16].

The second issue addressed when the idea of Lego is introduced, is that observation is theory-laden. What one 'sees' depends on prior knowledge and experience. A physician is likely to 'see' different/more things on an x-ray than an average person.

The latter issue does not only address an important aspect of NOS, it also provides insights in the pedagogy of practical work. What we, teachers, expect our students to see, what is obvious to us, is not always so obviously seen by students. This is true for making observations (that is why students ought to draw a cell they see when looking through a microscope in biology) but also for drawing conclusions [17].

A third issue can be addressed when the idea of Lego is introduced, namely the importance and use of argumentation in scientific inquiry [18, 19]. Although in the workshop this issue is addressed with the Tricky Tracks activity, this activity would in the classroom this would be a good place to discuss it as well. When the claim 'I hear Lego' is not further warranted, one can simply disagree. Making the claim more cogent, requires argumentation. The simplified version of Toulmin's [20] model of argumentation, presented in figure 4, helps in the support of the claim. In the actual classroom setting, you can provide the full argument and subsequently elaborate on each element, relating it to the Toulmin model.

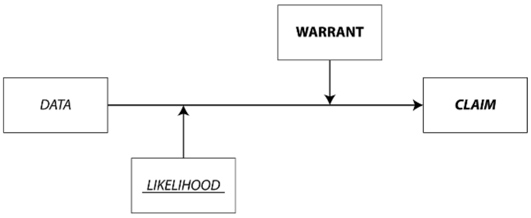

Figure 4. The simplified Toulmin [20] argumentation model can be used to help students structure their argumentation.

'I *hear multiple objects colliding with each other and a soft crackling*. The **sound is similar to the sound of boxes of Lego, of which I opened at least 100 when I was a kid. Based on** *the sound*, my experience, the *weight and size of the box*, it is *likely* that ***there is Lego inside***'.

Although many other valuable lessons are 'hidden' in this activity (and what is valuable to the participants, clearly depends on their prior experience and knowledge), I want to highlight one final issue, the purpose of scientific inquiry and the drawing of conclusions. Students have difficulties in drawing conclusions. In many scientific inquiries, they merely restate their results [21]. In most of the cookbook style practicals only one conclusion is sought (the one that the teacher has in mind) or merely a single 'right' conclusion can be drawn. Students are seldom asked to come up with multiple competing explanations for a produced phenomenon and subsequently discuss what explanation has the most potential, what other experiments can or should be devised to rule out some of these hypotheses [22]. However, a valuable idea in NOS is that often there are many possible conclusions, that one has to look for the most informative conclusion that is still supported by the data [23].

5. Conclusion

In this paper I elaborated on a NOS activity developed for the purpose of physics teacher professionalization. It includes various valuable ideas that need to be taught in science education. Although the activity here is described in the context of a professionalization workshop, it can easily be adapted to make it suitable for even students aged 13. Just put the box in the middle of the classroom and embark on an exciting science journey. If you want to drive home a point that drawing conclusions is more than just restating results, the box is a good 'box-of-departure' for further discussion. Important in this, is that what is really inside, remains hidden to those who participate in the activity. It is just another example of an idea from NOS: that our knowledge is limited and we cannot always be certain about everything.

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Ethical statement

This paper involves anecdotal data obtained from several workshops given by the first author. No personal data was collected and the work cannot lead to identification of the participants in the workshop. The participants gave explicit permission for the photographs to be published.

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