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Working with the nature of science in physics class: turning 'ordinary' classroom situations into nature of science learning situations

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Abstract

In the science education research field there is a large body of literature on the 'nature of science' (NOS). NOS captures issues about what characterizes the research process as well as the scientific knowledge. Here we, in line with a broad body of literature, use a wide definition of NOS including also e.g. socio-cultural aspects. It is argued that NOS issues, for a number of reasons, should be included in the teaching of science/physics. Research shows that NOS should be taught explicitly. There are plenty of suggestions on specific and separate NOS activities, but the necessity of discussing NOS issues in connection to specific science/physics content and to laboratory work, is also highlighted. In this article we draw on this body of literature on NOS and science teaching, and discuss how classroom situations in secondary physics classes could be turned into NOS-learning situations. The discussed situations have been suggested by secondary teachers, during in-service teacher training, as situations from every-day physics teaching, from which NOS could be highlighted.

1. The relevance of 'nature of science' perspectives for science/physics teaching

How certain is scientific knowledge? How can the relation between scientific models and nature be described? What does a research process look like? What is the role of experiments? Is the research process objective and rational, or are there also subjective and creative elements? How can the relation between science and the surrounding society be described? Are there limits for science, or will science in the future be able to answer all types of questions? These questions, and many more, all deal with 'nature of science' (NOS). Thus we use the concept of NOS in a broad sense including also socio-cultural aspects (see Lederman 2007, Erduran and Dagher 2014).

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The research field of science education has for a long time, and with numerous arguments, advocated that these kinds of NOS perspectives should be included in science teaching (e.g. Lederman 2007, Hodson 2009, Matthews 2012). Research shows that students often have views about science that are too simplistic. McComas (1998) speaks about the presence of a number of myths about science. Such myths include that the researcher always uses one specific research method—'the scientific method', that the research process relies more on procedures than on creativity, and that scientific research is an entirely objective and universal enterprise (independent of the researcher as well as of the surrounding society). When the 'scientific method' is followed, according to such a stereotypical picture, the research process results in absolute, objective facts about nature. These kinds of myths are reproduced in various situations, for example in school.

The myths described above are not challenged if the teaching only focuses on physics concepts and models, or through involving students in traditional laboratory work, without also explicitly discussing what kind of enterprise science is (e.g. Lederman 2007). That is, NOS-learning does not happen automatically, but has to be a learning goal that is planned for. The differences between the goals of learning science, learning to do science and learning about science (NOS) is discussed by Hodson (2014); it can be difficult to have all three goals in focus all the time.

Today there is a great focus on teaching science for citizenship (Hodson 2009). Also for this reason NOS knowledge is of central importance, e.g. as a tool when interpreting media reports. NOS knowledge could help students understand: why knowledge sometimes changes while there also is a high credibility and certainty concerning other knowledge, why researchers do not always agree on debated issues, and how the limits of science can be viewed upon. In addition to these reasons for including NOS in science/physics teaching, research also shows that NOS teaching can increase students' interest in science, as well as contribute to a better understanding of concepts and models (e.g. Lederman 2007).

NOS is part of science curricula in many countries, and has been so for more than a century (Jenkins 2013). However, despite research arguing for an inclusion of NOS in science teaching, and despite its inclusion in curricula, there is no tradition working with NOS in the science classroom (Lederman 2007). Instead, science teaching is still focused on what teachers speak about as 'facts and labwork' (Leden *et al* 2015), in which broader perspectives on NOS are seldom included.

Among scholars, scientists as well as philosophers and sociologists, there are different views of what characterizes science. However, regardless of disagreements, and differences between scientific disciplines, there are suggestions from different scholars of a number of NOS aspects or NOS categories that could be considered appropriate for K-12 students (e.g. Osborne *et al* 2003, Lederman 2007, Erduran and Dagher 2014). Such suggestions could function as guidelines for teachers. They can also, at least partly be viewed as a response to stereotypical and mythical pictures of science, as well as an attempt to change these pictures.

2. Research on how to work with NOS in science/physics classes

There are roughly speaking two main ways suggested in the research literature on how NOS could be addressed during physics lessons—separate from or connected to specific physics/science content. Separate NOS-activities could be a fruitful way to highlight specific issues, while teaching NOS in connection to specific concepts and models provide possibilities for NOS to become part of physics teaching not only during single lessons.

The latter approach could be done through addressing some NOS aspects in connection to: laboratory work (especially when the laboratory work is designed more like authentic science (e.g. Yacoubian and BouJaoude 2010, Etkina, 2015); historical examples (e.g. Höttecke *et al* 2012), or when working with 'socio-scientific issues' (e.g. Eastwood *et al* 2012) often (but not always) including frontier science. See Allchin *et al* (2014) for a discussion of different approaches to NOS teaching and how these could complement each other. In this way NOS becomes something that is discussed and learnt together with scientific concepts, models and procedures.

Both ways of dealing with NOS (separate and in connection to other physics content) have benefits and constrains, and they could preferably be used in combination (Clough 2006). However, it is important not only to teach NOS as separate activities, but also on the spur of the moment in connection to specific physics/science concepts and models (Nott and Wellington 1998, Herman *et al* 2013). Such NOS teaching also makes it possible to highlight the complexity of science (Clough 2006).

Below we will discuss how NOS could be brought to the fore during 'ordinary' physics lessons even if the main goal is not NOS learning. The situations discussed were collected in physics classrooms, by in-service science teachers, during a physics training course, and suggested by them as possible starting points for NOS discussions. From the teachers' hand-ins, we have for this article chosen four situations and suggested NOS topics that are possible to discuss. Thus the aim of this article is to discuss how such situations from ordinary secondary physics classes, can be turned into situations where classroom communication is widened to include NOS-perspectives, so that stereotypical and mythical pictures of physics/science can be challenged.

3. Examples of how classroom situations can be turned into NOS-learning situations

The situations discussed below are chosen with the intent to show a wide variety of possibilities for NOS to be highlighted in the physics classroom, in very different situations—e.g. both in teacher-led situations and during laboratory work, and both in relation to frontier and consensus physics. The situations are translated quotes from the teachers' hand-ins.

3.1. Situation A: surely there is another planet outside Pluto?

It has been reported in media that Pluto 'is no longer a planet'. Thus, this is a familiar issue to many students and teachers. The question above is not explicitly about whether Pluto is a planet, but instead about the possible existence of more planets outside Pluto. However, these two things are related. In this situation it is possible to discuss with the students that these questions concern the definition of a planet. A definition is something that is decided on by humans; in this case definitions in astronomy are set by the International Astronomical Union (IAU). Definitions could always be made in different ways. The concept 'planet' was introduced by the ancient Greeks, but through history the meaning of the word has changed and included different objects at different times (Tignanelli and Benétreau-Dupin 2014). At the beginning of the 2100 century astronomers had empirical data on more and more objects outside Neptune, which could all potentially be viewed as planets (Tignanelli and Benétreau-Dupin 2014). The need for a strict definition became more and more apparent, and in 2006 a definition was set by IAU, by a majority vote (Tignanelli and Benétreau-Dupin 2014). According to this Pluto is not a planet. In this case, Pluto has not changed, nor the knowledge about Pluto, only the definition of what constitutes a planet.

There are also plenty of opportunities to discuss the empirical work of astronomers, and how the concept 'planet' was challenged by new data. It is also possible to highlight that definitions of concepts are made by humans, and can be made in different ways. This is relevant not only for this case. Scientists in all different kinds of areas (present or far back in time) have been involved in categorizations of different kinds. This is part of the NOS. In some research areas, as in the case of astronomy above, this is very much the case today, while in other research areas, categorizations and definitions are agreed on and no longer up for discussion. It could also be highlighted that the definition made in 2006 might not be final, but could be changed again to resolve other problems. Also, as often, when humans are involved, some astronomers disagree about the definition set in 2006, and suggests other ones instead (Tignanelli and Benétreau-Dupin 2014). This could be viewed as an example of controversies, ongoing discussions and argumentation in research communities. Such aspects of knowledge-in-the-making is also part of the NOS, but is often not highlighted in the teaching of physics or in physics textbooks aimed for schools, where most often consensus physics is in focus.

3.2. Situation B: why is there so much research about cancer?

Research about cancer is a vivid area within different scientific disciplines involving not only medical researchers, but also physicists, chemists and many other experts. Such a research area, including collaborations between researchers with different disciplinary backgrounds, is an example of how traditional discipline boundaries are sometimes transgressed. Changing and transgressed disciplinary boundaries could also be viewed as part of what characterizes science, and thus part of NOS. Questions about why some research areas receive special attention are complex, but still possible and important to discuss in the classroom. Teaching could highlight that the special attention could be due to theoretical and/or empirical reasons. Another possible topic is research funding. Also such topics are part of a wide definition of NOS (see e.g. Erduran and Dagher 2014). Today, most researchers need to apply for research grants to finance the research. Some of these grants are public funding, but much of today's research is privately financed e.g. by industry or foundations. That researchers apply for grants in competition with other researchers, also means that trends and values in society play role for what projects get funded. Some areas enjoy a more favorable funding situation than others. For example in cancer-related research, the industry could have a specific interest due to possibilities of developing and profiting on medicine. It is also an area that most of the general public find important. Thus funding is possible both from e.g. the pharmaceutical industry, as well as from non-profit organizations collecting money from the general public.

3.3. Situation C: our textbook says that sound waves are compressions and rarefactions of air. How certain are researchers about this?

In this situation the starting point for the possible NOS discussions is from consensus, school-book physics. A possible focus could be how the current understanding of sound has developed. An historical overview could be provided over how ideas about the transmission of sound have developed. The idea has its origin far back in history. Aristoteles, for example, viewed sound as waves, and states that air has to be pressed together for the sound to move (Caleon and Subramaniam 2007). However, during the first half of the 1600s there were still researchers who viewed sound as a movement of matter from one place to another, e.g. a flow of particles is sent from the source (Caleon and Subramaniam 2007). Empirical support for a view where transmission of sound is about matter movement, but not about net displacement was first put forward by Boyle and Hooke. They used a vacuum pump connected to a jar with a bell inside. When air pressure dropped, the sound of the bell died out (Caleon and Subramaniam 2007). Due to this empirical support consensus could be reached about the need of a medium for the transmission of sound. Such an historical account of how ideas about sound have developed, places empirical as well as theoretical parts of the research process in focus. However, care must be taken so that historical cases are not taught in a simplistic way, reinforcing myths about science (e.g. Allchin 2003).

In this way classroom discussions could also focus on reasoning and arguments in science, not only on 'facts'. Thus science can become more than just another 'fairy tale'. With the starting point in this situation, the NOS discussion could also focus on certainty/uncertainty as well as continuity/change. Scientific knowledge is always open for change. Models could be fine-tuned, or, more rarely, substituted. However, theories and models do not change randomly. Most of the models scientists use today will also be in use when the students are adults (and even old). It is also important for students to know that a specific model will work as well (or bad) in the future as it does today. However other models could in the future be constructed that give more accurate results, provide a new way of viewing old data or unify different descriptions.

3.4. Situation D: lab work on heat transport

The students were to investigate which material is the best heat transporter (lead, aluminum, brass or iron). They put forward different hypothesis: Lead transports the best because it has the highest density /…/, iron transports the best because it is a good electrical conductor. They were to design the experiment by themselves with the help of a tea light, and they proceeded in different ways. Some students held the metal rods in pairs and felt which of them warmed the fingers the fastest /…/ (like a knockout competition).

> *Some of them took one rod at a time and used a stopwatch. Some tested all of them at the same time, but were two persons holding two rods each over the candle. The interesting thing about the task is that they all got different results!* (a teacher's description)

In this situation students are engaged in open inquiry. Parallels could be drawn both to the work of researchers, e.g. that creativity is needed in the research process (in different phases of the investigation—e.g. when formulating research question, when planning the investigation (e.g. experiments), and when interpreting results), and to the relation between empirical and theoretical work (see above). Differing results also open up numerous possibilities for discussions. One topic for discussion is that in science you expect to get similar result if the same investigation is repeated, by another person or in another place (AAAS 2009). This is due to science presupposing that nature is ordered, which also is something that could be necessary to discuss with the students (Hansson 2014). That nature is ordered is the reason for why we expect a general answer to the question about which of the metals transports heat the best. When this background has been established students can discuss which method is likely to lead to the most trustworthy results. They can test each other's methods, or develop new ones. Science as theory laden is also an aspect that could be discussed (e.g. different starting points resulting in different ways of investigating and interpreting), as well as the relationship between observations and conclusions (e.g. relating their observations to an evaluation of their hypothesis). Students can present their methods, results and conclusions to each other, and engage in a critical examination of their own and other students' results. Then parallels to research conferences and the peer review system in the research community could be drawn. To, in physics class, engage students in work similar to the work of researchers has been found very fruitful at different levels of the educational system (Etkina 2015). There are examples, in the literature, of how explicit NOS-discussion in authentic inquiry could improve students' NOS understanding (e.g. Yacoubian and BouJaoude 2010, Abd-El-Khalick 2013). However, it is important to notice that also in situations where students are involved in authentic inquiry contexts, NOS has to be explicitly discussed (Abd-El-Khalick 2013). The situation described above, is not authentic in this respect, but part of traditional school labwork. However, there are still, as discussed above, possibilities to discuss some NOS aspects in relation to such traditional labwork.

4. Conclusion

Science education researchers have argued for the inclusion of NOS perspectives in science/physics teaching. This can be done in different ways (e.g. as separate NOS-activities or setting up authentic inquiry lessons where NOS is explicitly discussed and planned for etc), but Herman *et al* (2013) argue that it is also important that teachers are able to connect NOS to other science/physics content, as soon as possibilities are given. Sometimes this can be planned for, but it also has to do with teachers' competence to seize the moment. This could be during lessons having the goal that students learn: physics content, processes of scientific investigations, or how to use science knowledge when engaged in socio-scientific argumentation. To, in this way, not teach NOS only through isolated activities, but also in connection to other content and goals, creates possibilities to highlight the complexity of science (Clough 2006). Thus, there are opportunities to leave stereotypical and mythical pictures of science behind. And students can be provided possibilities to engage with a science that is not only 'ready-made' and created by others, but a vivid area in which they themselves can engage. The aim of this article has been to, with a starting point in some concrete situations retrieved by teachers in their everyday practice, illustrate how this could happen. That is, how 'ordinary' physics teaching situations could be seized and turned into NOS-learning situations.

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