

WHY, WHEN AND HOW TO TEACH NATURE OF SCIENCE IN COMPULSORY SCHOOL – TEACHERS’ VIEWS

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Abstract: The inclusion of “nature of science” (or NOS) in science education, has for a long time been regarded as a crucial component in the teaching for scientific literacy. Research has shown that teachers in general do not possess adequate NOS-understanding and are therefore not able to perform adequate NOS-teaching in the science classroom. The aim of this study is to investigate in-service science teachers’ views of NOS, and their views of why, when and how to teach NOS. The participants in the study are Swedish in-service science teachers (n=12) in grades 4-9. Sources of data are questionnaires and interviews. The analytical framework used in this study is inspired by the NOS tenets described by Lederman (2007). The preliminary results indicate that the teachers express uncertainty in their own knowledge of NOS and the teaching of NOS. They also express that aspects of science as a subjective, socially and culturally embedded endeavor are aspects that are abstract and difficult for young students (K-3) to grasp. The study is part of a larger project where the teachers will be studied for three years in their science teaching as well as taking part in focus-group discussions concerning NOS and the teaching of NOS, guided by a researcher. The results may also be used in teacher-education programs and in teachers’ professional development, where an emphasis on NOS could help teachers’ develop strategies for the teaching of NOS. This, in turn may lead to increased possibilities for students to meet all standards in the national curriculum.

Keywords: nature of science, science education, teachers’ views

INTRODUCTION AND BACKGROUND

Science education researchers has for a long time been advocating the inclusion of the nature of science (NOS) in science teaching and in curricula (Cobern, 2000; Matthews, 2012; McComas, 1998a; Osborne, Collins, Ratcliffe, Millar & Duschl, 2003). The impact of NOS in science curricula in the western world is explored by Jenkins (2013) who claims that some aspects of NOS have been part of the agenda for more than a century. Much has been written about teachers’ views of NOS and how NOS is taught in the science classroom, but little is known about the teachers’ views of the teaching of NOS. To be able to better understand why and how NOS becomes a part of science education, teachers’ views of the teaching of NOS needs to be empirically investigated.

Arguments raised for including NOS in science education are for example: NOS as a crucial component of scientific literacy (Driver, Millar, Leach & Scott, 1996; Hodson, 1985; 2008; 2009), NOS as a facilitator to deeper understanding of the science content (McComas, 1998a), and NOS as a motivator and contributor to students’ interest especially if this means that there will be a decreased focus on memorizing facts (McComas, 1998a; Sjøberg, 2010). In addition to this Duschl, Erduran, Grandy and Rudolph (2006) argue that science education continues to have a narrow focus on logical and conceptual elements – that science education has been blind to broader perspectives on NOS. Therefore another argument for including NOS in science education could be to challenge what Carlone (2003) calls “prototypical science”. That is, NOS-instruction could open up possibilities to challenge and break the reproduction

patterns where science through the teaching of science is reproduced as an objective, privileged way of knowing pursued by an intellectual elite. These patterns which are part of taken-for-granted practices in science teaching are undermining “the goal of “science for all”” (Carlone, 2003, p.308)

Among scientists, philosophers of science, and in the field of science studies there is a long-term debate on what nature of science is and if there even is a nature of science (Alters, 1997; Eflin, 1999). While Alters argues that there is no NOS, Eflin, on the other hand argues that there is agreement on a number of NOS topics both within and across different scholarly disciplines. Science education researchers are not exempted from the debate over the meaning of nature of science and they have dealt with this question in somewhat different ways. A main focus of the debate has been how and what NOS-content should be taught in school. One of the approaches is to create lists of tenets on topics for which there is great agreement on the relevance to K-12 students (see for example Lederman, 2007; McComas, 1998a; Osborne et al., 2003). These kinds of tenets and consensus lists have had great impact on science documents such as for example the *Benchmarks for Science Literacy* by the AAAS (Van Dijk, 2011). An elaboration of the tenets is discussed by Matthews (2012) who advocates a change from nature of science to *features* of science and thereby argues that this opens up for elaboration, inquiry and discussion instead of the risk of just memorizing tenets. Abd-El-Khalick (2012) agrees that there is a need to elaborate on these aspects of NOS. Especially when teaching students in higher grades it is important to discuss and reflect upon the complexity and the intertwining of NOS-tenets. Other researchers advocate a family resemblance approach to NOS instead of using tenets which could contribute to providing a simplistic or to general picture of science (Eflin, 1999; Irzik & Nola, 2011; Van Dijk, 2011). With the family resemblance approach categories described by Irzik and Nola (2011) both heterogeneity and resemblances between scientific disciplines are emphasized. In these categories there is a greater focus on scientific activities, methods and methodological rules, while there is a lesser focus on social and cultural aspects of science compared to the approaches described by Lederman (2007) and Matthews (2012). Duschl, Erduran, Grandy and Rudolph (2006), and Eflin (1999) argue that studying science from a range of different disciplinary bases such as philosophy, sociology, psychology and cultural studies of science, can contribute to the characterization of science and help elaborating on the perspectives on NOS.

Different opinions on how to teach NOS have been presented by several researchers within this domain. According to Lederman (2007) NOS is “best learned through explicit, reflective instructions”, but whether these explicit instructions should be embedded within traditional subject matter or be taught as a separate “pull-out” topic is still up for debate. The explicit approach to NOS is described by Wong and Hodson (2010) as NOS considered as content that should be carefully and systematically taught through giving students opportunities to reflect on NOS issues. Opposed to explicit teaching is implicit teaching which comprises implicit messages about NOS embedded in teacher language or in classroom activities. Other researchers like Allchin (2011; 2012) and Duschl and Grandy (2012) focus strongly on teaching *about* science while *doing* science. They also emphasize the importance of NOS being taught *within* in the context of a topic (e.g. mammogram) and strongly focus on meta-reflection, analytical skills and discursive skills.

Science education research has primarily been concerned with investigating teachers’ and students’ views and beliefs about NOS. Research has shown that logical positivism has had (and still has) a strong influence on science education (Carlone, 2004; Cobern, 2000; Duschl et al., 2006). Assessing science teachers’ and students’ views on NOS have shown that science is thought of as a body of knowledge consisting of proven facts and that there is one

single structured way to gain this knowledge (Lederman, 1992; McComas, 1998b). Some of the research has had a focus on changing teachers' views of NOS (which has been shown to be difficult) (Abd-El-Khalick & Lederman, 2000). Matthews (2012) argues that it is unrealistic to expect students or teachers to be experts in history, philosophy or sociology of science but the aim should be to have a more complex understanding of science than is usually the case today. In classroom studies the views of NOS that are communicated by the teachers and the connections between teachers' views of NOS and their classroom instruction have been investigated (see for example Brickhouse, 1990; Clough & Olson, 2012; Lederman, 1992). Some studies show that even if teachers have knowledge on a large number of issues concerning NOS this knowledge often does not have an impact on the teaching of NOS. But on the other hand it is believed that without teacher knowledge about NOS there is not even a possibility to provide students with an opportunity to discuss reflect and elaborate their knowledge of NOS (Lederman, 2007)

From this body of research we know that students' as well as teachers' have problems discussing and elaborating different NOS topics and that even if the teachers have considerable knowledge of NOS, the prototypical science is seldom challenged in the science classroom. This article takes as a point of departure that science teaching could benefit from challenging the way science is traditionally communicated and that this could provide one way to make more students feel included in the science classroom. In this perspective teaching about NOS in compulsory school, in a science for all perspective, becomes central. If we believe that it is important to elaborate, question or challenge the traditional views of science in the science classroom we need to know more about teachers' views of the teaching of NOS. However, research on teachers' views of the role of NOS in their own teaching and in a K-9 perspective, as mentioned above, is very scarce. Therefore this study seeks to comprehend and shed light on how teachers speak of why, when and how NOS should be taught at different levels in compulsory school and how this can be reflected in their views of different NOS-aspects.

The ambition of this study is to contribute to the development of strategies for what to focus on in science teacher education, and in-service science training, regarding the teaching of NOS, so that NOS in the future will be included in the teaching of science as one way of challenging the traditional images of science usually communicated in science class.

The questions guiding this study are:

- How do teachers speak about different aspects of NOS?
- How do teachers speak about the teaching of NOS in a year 1-9 perspective?

METHODOLOGICAL PERSPECTIVES

The study reported on here is part of a larger project where 12 teachers (two groups) will be studied for three years both while taking part in group discussions guided by a researcher and in their science teaching.

Study context

In the current Swedish national curriculum Lgr 11 (Skolverket, 2011), as in most other western countries, there is an ambition that students should learn NOS (Johansson & Wickman, 2012). In the current national curriculum the references to NOS are less explicit than in the previous curriculum. Therefore, at the starting point of this study, we used the

VNOS-C (views of nature of science) questionnaire (Lederman et al., 2002) with the purpose to familiarize the teachers with the forthcoming discussions about NOS.

Participants and data collection

12 teachers, teaching in school year 4-9, who volunteered to participate in the project, first answered the VNOS-C questionnaire. Before using the questionnaire it was translated into Swedish. Four researchers translated the questionnaire independently and then compared, discussed and moderated their translations into a final version. A couple of months after the questionnaire was answered the teachers were interviewed about their views on NOS (while having access to their formerly written answers) and their opinions on NOS in science teaching. The teachers were asked to describe if and how they teach NOS today and give their opinions on why, when and how NOS should be taught at different levels in compulsory school. The interviews were semi-structured and the questions were guided by five different themes described below. The interview was divided in two parts where the teachers during the first part was asked to elaborate on their answers from the questionnaire in new contexts and with more examples, while the second part involved issues about the teaching of NOS. All interviews were digitally recorded and transcribed.

Framework and analysis

The analytical framework used in this study, inspired by the NOS tenets described by Lederman (2007), is constituted by five NOS-themes (described below). The themes are employed as thematic lenses in the analysis of teachers' ways of speaking about aspects of NOS inherent to each theme. Using these lenses is a way to identify how teachers' use different ways of speaking about NOS, both in ways closely related to what Carlone (2003) called "prototypical science" and what McComas (1998b) relates to as "the myths of science", and in ways of speaking that problematize this way of picturing science. The themes are therefore treated more as features of science (Matthews, 2012), open to including a broad span of possible ways of speaking coupled to different topics both relating to science in general and to specific scientific disciplines. The theme descriptions (below) are based on science studies literature as well as science education literature (see above).

In a first phase of the analysis teachers' ways of speaking are sorted under the different themes.

1) Absolute and/or tentative nature of science

From the science studies literature as well as from the science education literature (see above) we know that a variety of topics, such as continuity/change and certainty/uncertainty, are relevant in relation to this theme. Ways of speaking coupled to both historical and contemporary contexts related to this theme, could possibly range from scientific knowledge being absolute and static facts to scientific knowledge being tentative, random and uncertain.

2) Empirical and/or rational science

Using this thematic lens we look for teachers' ways of speaking about the role of empirical results in science, for example deriving from observations and experiments, as well as their ways of speaking about theoretical results. From the philosophy of science literature we know that different emphasis on empiricism respectively rationalism are possible, but we also know from the science education literature that the empirical base is most often emphasized in the teaching of science through "the scientific method" (McComas, 1998b). From the science

studies literature we also know that there are different ways to view the scientific endeavor/processes and how results are produced and criticized by the scientific community. Topics relevant for the theme are the role of observations and experiments, trustworthiness, and methods and limits of science. Ways of speaking could be connected both to general and discipline specific features of science and range from the idea of one specific universal method leading to absolute truth (observations automatically providing truth), to the notion of great diversity (and even messiness) in methods and between disciplines.

3) Subjective and/or objective science

In this theme ways of speaking can range from realism to constructivism and it includes a wide variety of areas such as ontology and epistemology of science, sociology and psychology. A number of topics, like for example discussions of subjectivity/objectivity connected to different stages of the research process, theory-laden/neutral observations, background factors and bias, belong to this theme.

4) Scientists as creative and/or logically rational

In this theme views can range from scientists using a well-structured predesigned approach, never deviating from *the* (objective) scientific method to the necessity of using creativity and imagination throughout the entire research process (from problem stating to interpreting observations and inventing explanations)

(5) Socioculturally embedded and/or universal science

This theme comprises the controversial and much debated continuum extending from everything is science to everything is culture (science wars). With this thematic lens we look for teachers' ways of speaking about issues and perspectives that are covered by this continuum. These issues could be about the extent to which science is influenced by society/culture, and the extent to which science is universal. It could also be how teachers use perspectives ranging from realism to relativism. Both historical and contemporary contexts contribute to these issues from a number of perspectives (e.g. economy, politics, religion, philosophy, feminism).

In a first step, teachers' ways of speaking about NOS and their ways of speaking about the teaching of NOS were analyzed with the different themes described above as a framework. Teachers' ways of speaking concerning each of the themes were extracted through repeated reading of the transcripts. In a second step, teachers' ways of speaking about NOS and the teaching of NOS were analyzed looking for different ways of speaking about NOS as well as about NOS-teaching within each theme. Important to recognize is that, for all of the themes, the same teacher can express different views on different occasions both in the questionnaire and in the interview.

RESULTS – TEACHERS' WAYS OF SPEAKING ABOUT DIFFERENT NOS THEMES

In this section different ways of speaking about NOS connected to teachers' ways of speaking about the teaching of NOS will be presented. In the table below an overview of teachers' different ways of speaking about the five themes are presented. One teacher often has a wide range of ways of speaking about NOS connected to each theme. For all themes the teachers express views of science as following a structured, objective scientific method leading to absolute truth. For some of the themes there is a broader repertoire in use when discussing

science. For other themes there are fewer ways to speak about NOS. This is particularly apparent for one of the themes – empirical/rational science.

Table 1

Overview of teachers' different ways of speaking about NOS

<i>Absolute/tentative</i>	<i>Empirical/rational</i>	<i>Subjective/objective</i>	<i>creativity/logically rational</i>	<i>Sociocultural/universal</i>
Scientific knowledge is absolute	The scientific method is used by every scientist	Scientific knowledge is objective	Scientists use a well-structured approach – the scientific method	Science is universal
Progression in knowledge	Researchers will plan their investigations in different ways and then argue and write about their results.	Scientific knowledge can be slowed down by subjectivity.	Scientists are creative when designing and planning investigations	Science can be limited or slowed down by social or cultural aspects
Scientific knowledge is subject to various degree of change		Science is both theory-laden and influenced by the researchers personal subjectivity	Scientists are creative when designing and planning investigations	Different researchers from a variety of places is favorable to the development of scientific knowledge

The preliminary results from two of the five themes, *tentative/absolute science* and *creativity/logically rational science*, are presented below. The analysis of the other three themes is ongoing and will be presented elsewhere.

Absolute and/or tentative? – ways of speaking about science and teaching

We have identified three different categories of ways of speaking about tentative/absolute science (an overview is presented in table 2). The categories range from descriptions of scientific knowledge as absolute, static and proven facts about nature (examples provided by the teachers are school science and scientific laws), to descriptions of scientific knowledge as always being subject to change.

Most of the teachers claim that even if science is subject to change it is still truer than other ways of knowing.

Bert: In other sciences (humanities, social sciences) you deal with opinions and believes which can be changed. In natural sciences you deal with provable causalities.

Some science is also “truer” than other science. This is for example the case when it comes to school science, which is not considered to be as much subject to change as other parts of science. In the second category there is a strong emphasis of science as progressive, providing us with better and truer knowledge. A common example is the change from a geocentric world view to a heliocentric world view. Other examples are more unspecific and describing the notion of changes from the teachers’ own childhood until today. In the third category teachers speak about science as tentative due to a variety of reasons such as new questions, new instruments, new findings, influence from new people with different backgrounds, coincidence, reevaluations etc.

The different categories described above can be related to teachers’ ways of speaking about how science is or can be addressed in the science classroom. Teachers’, in the study, often describe their classroom instruction as a teaching of facts.

Linda: I’m not good at discussing tentativeness – that maybe scientific knowledge is changing and not static. I only do experiments and facts. And drawing conclusions.

At the same time some of them are questioning this practice and wish to change it. On the other hand some teachers say that in school it is necessary to teach science as black and white although they believe that this differs from science in reality. The black and white teaching is considered to facilitate students’ learning. Other teachers emphasize the importance not to teach science as black and white and also state the importance for students to know that things are not just right or wrong (white or black) to better be able to cope with everyday science issues and as a way to maintain students’ curiosity. The usual example brought up by the teachers’ is the geocentric world view and this is one of the few examples considered easy to teach at all levels in the educational system. Other common examples are teachers referring to scientific knowledge that has changed since they themselves where young.

An overview of teachers’ ways of speaking about the *absolute/tentative nature of science* compared to how they speak about ways to address this in the science classroom is presented in the table below.

Table 2

Teachers’ ways of speaking about the absolute and/or tentative nature of science nature of science and the corresponding teaching

<i>Ways of speaking about absolute/tentative science</i>	<i>Possible ways to address absolute/tentative science in the classroom</i>
absolute	Teaching about facts and the scientific method leading to proof.
Progression	Historical examples given in the classroom (geocentric worldview). Examples of progression. Teachers referring to their own experiences of change
Various degree of change	Not addressed

Teachers speak of tentative aspects of science as important in the science teaching to make students aware of the lack of an absolute (but, by the students, sometimes cherished) truth. By most of the teachers this theme is considered easy and graspable. And by using historical examples (however, there is a lack of contemporary examples) it can be taught throughout the entire compulsory school.

Carolyn: They should know there are different ways of understanding science and that it is actually not static. It is not like someone has said something or come up with something and that something cannot change. It can always change and that ought to be challenging and exciting for the kids to know. They can get an interest in science because they feel that this is not just something they have to memorize, but instead they have to think for themselves.

Creative and/or logically rational – ways of speaking about science and teaching

The teachers' ways of speaking about human creativity in relation to science range from the need to follow the structured approach provided by the scientific method (and also speaking about a danger in scientists being creative), to creativity as an important part of all stages in a scientific investigation. Three different categories regarding ways of speaking about creativity and science have been identified (an overview is presented in table 3). When explicitly asked, all of the teachers (with one exception) are convinced that creativity and imagination is an important part of the development of scientific knowledge. First and foremost creativity is essential in planning investigations and the scientist has to have an open mind to be able to "look outside the box" and find the best way to elicit the truth. On the other hand while speaking about the scientific method with fixed ways of doing science the teachers implicitly present a picture of science as absent of creativity. Discussions of creativity while interpreting observations range from the importance of just looking at the data and letting it speak for itself, to the absolute necessity of being creative in your interpretations and conclusions if the data shall be of any use at all. John has provided two very different ways of speaking about creativity in relation to experiments and observations.

John: Well, I assume that scientists use their creativity and fantasy. In my point of view, if you are not creative, you cannot build a theory that you in some way test with an experiment that you design. I'm having a hard time imagining that it would work at all if you totally lacked fantasy. Otherwise everything would be guided by chance. That you happen to come up with something like, what's their name Curie or Becquerel or Röntgen or something, who of course discovered X-ray by chance, but without fantasy he would not be able to think further – What could this be and how can we check this? Without fantasy you would just drop it in the waste basket and then just, well that's a pity on those photographic plates. So I would say fantasy is quite central in science.

John: experiments make it concrete and possible to grasp. This is what it is like. You just have to look. Open your eyes and look.

The teachers' ways of speaking about science teaching can be related to the three previously described categories. The creativity in science is implicitly taught when students themselves are creative in their planning of investigations and in their discussions of results. This is regarded by the teachers as an important but neglected part of science education. Reasons for not opening up the classroom to students own planning and discussions are lack of time and a

fear that the goal of lab work contributing to the students learning of the right scientific concepts will not be fulfilled. Similarly the not so creative science is the most common way of teaching through predesigned lab instructions leaving little room for students' own reflections and considerations (discussed by Linda below).

Linda: Well, up till now, I have usually handed out a lab manual for them to follow. And then they are supposed to draw conclusions from that. But it is changing. I'll try to get better at giving them more open tasks, where they themselves will try to find out what to do. And then hopefully there will be discussions about that and then later on discussions about the plausibility in the results and sources of errors, but usually they follow a manual and they are supposed to come up with an answer.

Camilla and Mike (below) both refer to constrains (time factor, breakable equipment and content that need to be covered) related to letting students find out for themselves.

Camilla: I feel that both the time factor and that you are sometimes afraid that they will wreck the equipment, makes you restrict them. And maybe it is hard to get away from that thinking, although maybe you should give them (the students) some more space.

Mike: You feel that you have this busy schedule and that you have to get through this and this and then you feel... But maybe it is stupid not to make time for the students to try to find out for themselves how to do it? You feel that they just waste an entire lesson, but maybe it would be worthwhile doing so. Not every time but now and again.

Table 3

Teachers' ways of speaking about creative and/or logically rational science and the corresponding teaching

<i>Ways of speaking about creative/logically rational NOS</i>	<i>Possible ways to address creative and/or logically rational NOS in the classroom</i>
Scientists use a well-structured approach – the scientific method.	Students follow predesigned lab instructions.
Scientists are creative when designing and planning investigations	Students use their creativity while designing investigations.
It is necessary for scientists to use their creativity and imagination through the entire research process.	Students interpret and evaluate their own investigations.

Teachers speak of science and creativity as important in the science teaching as a way to increase student interest in science. All teachers regard aspects of creativity to be practical,

concrete and possible to address in connection to hands-on tasks throughout the entire compulsory school, although some of the teachers argue that students often have difficulties when expected to be creative.

CONCLUSIONS AND IMPLICATIONS

For all five themes the teachers in this study speak about science as following a structured, objective scientific method which leads to absolute truth. For some of the themes there is a broader repertoire to use when discussing science and for these themes the prototypical science (Carlone, 2003) is challenged, at least by the teachers' ways of speaking about NOS, even if it is not challenged to the same degree in their ways of speaking about the teaching of NOS. For other themes there are fewer ways to speak about science. This is particularly apparent for one of the themes, empirical/rational science, where the repertoire is narrow in both the ways of speaking about NOS, and (particularly) when teaching practices are discussed, especially when the teachers reflect on their own teaching as compared to when teaching in general is discussed. When it comes to the themes dealing with subjective/objective science and sociocultural/universal science there is only a very small repertoire of teaching strategies even if there is a quite broad repertoire of speaking and reflecting about these aspects among the teachers. There are only a few examples of how to address these aspects in the science classroom and they are perceived as abstract and difficult for students to grasp.

When teachers speak about the teaching of NOS it becomes obvious that even though it is common that they describe NOS-themes as important to address in science class, there are a lot of perceived hindrances for a reflective NOS-teaching to become a reality. First of all there may be limitations in the teachers' knowledge and repertoire when it comes to speaking and the teaching of NOS. Secondly, according to the teachers in the study, the science teaching tradition means that students are supposed to do lab work and learn scientific facts. Lab work is primarily performed as a way for students to learn important facts or "the scientific method". Thirdly teachers try to make the teaching of NOS fit within the described science teaching tradition which means that the teaching of NOS will be linked to lab work. According to the teachers the students will learn NOS by doing science (e.g. the students are supposed to be creative themselves).

For some of the themes, lack of knowledge and/or a small repertoire will be a hindrance, while for other themes this is not the bottleneck – in these cases (e.g. creative/logically rational theme) science teaching traditions easily becomes the hindrance instead. When the teachers speak about teaching, for example creative/logically rational NOS, they almost exclusively speak about whether it is possible or not for the students to be creative in science class (e.g. during lab work) - the teaching is supposed to implicitly make students aware that scientists are creative by letting students themselves be creative. Even if most of the teachers find student creativity, discussions and reflections important, there will be problems since it is time consuming and a distraction to the main purpose – introducing scientific facts to the students. However, important to notice is that teachers themselves problematize their teaching and speak about the need to elaborate their ways of teaching. For the two themes (absolute/tentative and creative/logically rational) described above, the teachers emphasize the importance of students learning that the world around them is not just "black and white"- that scientific knowledge should be separated from absolute truth.

The preliminary analysis reported on here implicates that teachers ways of speaking about why, when and how to teach NOS sometimes need to be challenged to help leave parts of the prototypical science behind, but it also indicates that teachers themselves have identified this need, but without knowing how to put their thoughts into practice. Knowing more about

teachers starting points contributes to the knowledge of where pre-service and in-service teacher education should have its point of departure for issues concerning NOS.

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