REFLECTING ABOUT THE NATURE OF SCIENCE THROUGH PHILOSOPHICAL DIALOGUE

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ABSTRACT

To increase the scientific literacy among students and to stimulate their critical reflection about science, educating about the Nature of Science (NoS) is crucial. NoS entails a focus on the central epistemological underpinnings of science, such as its realm and limits, its levels of uncertainty, its biases and the reasons for its reliability. Following the principles of design-based research we developed a teaching method to increase the understanding of NoS among (student) science teachers and to increase their didactic skills to address NoS in the science class. In our approach, the philosophical dialogue is used to elicit reflection about NoS. Observations and interviews of student teachers and teacher educators during and after the intervention show that the philosophical dialogue is promising as it helps to uncover preconceptions about science by making thinking explicit. However, mastering the philosophical dialogue takes time.

INTRODUCTION

Though we often hear the words "scientific proof" or "scientific certainty" in advertisements, journals or news broadcasts alike, the scientific reality is often much more nuanced. However, in order to understand these nuances a thorough understanding of the scientific process and its epistemological underpinnings is necessary. There is a need for school students to know about the 'nature of science' (NoS). NoS entails the epistemological underpinning of scientific knowledge, its levels of uncertainty, its realm and limits, its biases and the reasons for its reliability (N. G. Lederman, 2006). Explicit attention for NoS positively influences the conceptual understanding of science (Clough, 1997; Khishfe & Abd-El-Khalick, 2002), the critical sense and scientific literacy of students (Miller, 1998).
Understanding the nature of science helps to go against misconceptions about science such as: "I don't drink milk, because I heard a scientist on television say it isn't healthy." or "Since we cannot be 100% certain about every aspect of the theory of evolution, it must be wrong".

In this paper we investigate how to elicit explicit reflection about the NoS by implementing the method of the 'philosophical dialogue'. We focus on three research questions:

1. What is the nature of science?
2. What can be the merit of philosophical dialogue for NoS-education?
3. Which learning material allows addressing the nature of science in teacher training?
4. What is the attitude of students and teacher trainers with regard to NoS in teacher training?
5. Which context variables such as classroom organization and student characteristics influence the success of this approach?

Section 2 answers question 1, sections 3 tackles question 2 and question 3 till 5 are answered in sections 4 and 5. Finally the discussion is presented in section 6.

WHAT IS THE NATURE OF SCIENCE?

There are three aspects to science:

a. Science is in part the body of knowledge of scientific facts, laws, theories,… This aspect of science is addressed explicitly in all science classes and receives the most attention.
b. Science is also in part the scientific method of questioning, hypothesising, testing, and concluding (and repeating). Recently this aspect of science is receiving increasingly more attention in the classroom, through hands-on experiments, group projects,…
c. The third, and often forgotten, aspect of science involves knowing about the characteristics of scientific knowledge (N. Lederman & Abd-El-Khalick, 2002). The latter is referred to as the nature of science (NoS). NoS is often only addressed implicitly within the classroom. This is unfortunate as this lack of attention to NoS gives rise to a number of misconceptions about science and impedes the development of students critical thinking skills (Abd-El-Khalick, Bell, & Lederman, 1998; Akerson & Donnelly, 2010; N. G. Lederman, 2006).

NoS consists of many aspects, below a non-exhaustive list is presented:

- **Tentativeness** Scientific knowledge can and will change as new insights are obtained. Theories are adapted, laws are made more precise, a different classification scheme reveals new underlying principles,…
- **Empirically based** Empirical observations are a fundamental part of science.

- **No roadmap** There is no universal roadmap to doing science. This is true across different disciplines, a biologist approaches a question differently than a physicist, but also throughout history. New techniques are needed to advance science.
- **Observation ≠ interpretation** Observations are made by our senses, from these observations hypotheses are formulated adding an interpretation to the observation. The same observation, looked at with a different theory in mind, may lead to different interpretations.
- **Creativity** Formulating research questions, setting up a research design, formulating hypothesis, development of new research equipment,… all require the creativity of scientists.
- **Objectivity** While scientists strive for objectivity, science is still a human endeavour bringing subjectivity along with it. The choices a researcher faces are always answered from his point of view.
- **Historical and cultural context** Science is performed at a given moment in time, in a certain cultural context. This context will affect the choices and the execution of the research.
- **Social** Science is a group effort. Even research that is done by a single researcher only becomes part of the body of scientific knowledge after it has been shared (e.g. through a publication in a peer reviewed journal).
- **Technology** Science and technology are in constant interaction with each other. Advancements in one lead to advancements in the other and vice versa.
- **Ethics** While the applications that follow from scientific discoveries can have a positive or negative influence on the world/humanity, the scientific knowledge as such is neither good nor bad.

A PHILOSOPHICAL REFLECTION-METHOD TO DISCUSS NOS

As a matter of fact, each science lesson can be a lesson about NoS if attention is paid to the way scientific discovery takes place, the importance of observation and the relation between science and technology. Research of Akerson points out that explicit attention is needed for students to make connections between the science activity they are carrying out and the central aspects of NoS. If this does not happen, they will not get insight in the way science works (Akerson & Donnelly, 2010). To facilitate the way of teaching about NoS and reflection about NoS a specific way of asking questions and a specific method to stimulate discussion is proposed in this publication. The method is called philosophical dialogue and can be integrated within classic contextualized or decontextualized NoS-activities (Schjelderup, 2009). In a philosophical dialogue, a group of students discusses about a thought-provoking question by exploring the coherence and relevance of arguments. Dialogue is guided by the teacher who takes the Socratic stance, which means that no answers are given by the teacher, but only questions are asked to the participants (Wenning, Holbrook, & Stankevitz, 2006). This way, students are stimulated to develop their own thoughts and ideas (Lipman, 1991, 2003). Success of philosophical dialogue depends on the appropriate use of specific question categories by the teacher.

The method proposed in this publication consists of different steps (figure 1). It starts with a stimulus which can be contextualised or decontextualized and sparks reflection about the NoS. The stimulus is concretely realized in specifically designed learning material. The stimulus makes it possible to come up with a specific philosophical problem or question. In fact, philosophical dialogue always starts with such a philosophical problem or question. In the method proposed in this article the question arises naturally from the stimulus. Examples of such questions are: Is creativity important for a scientist? What is the difference between observation and interpretation? Can a scientist ever be sure? Are scientists' results subjective? These questions can drive an exploration into the realm of NoS. The questions can be formulated by the teacher, but also by students.

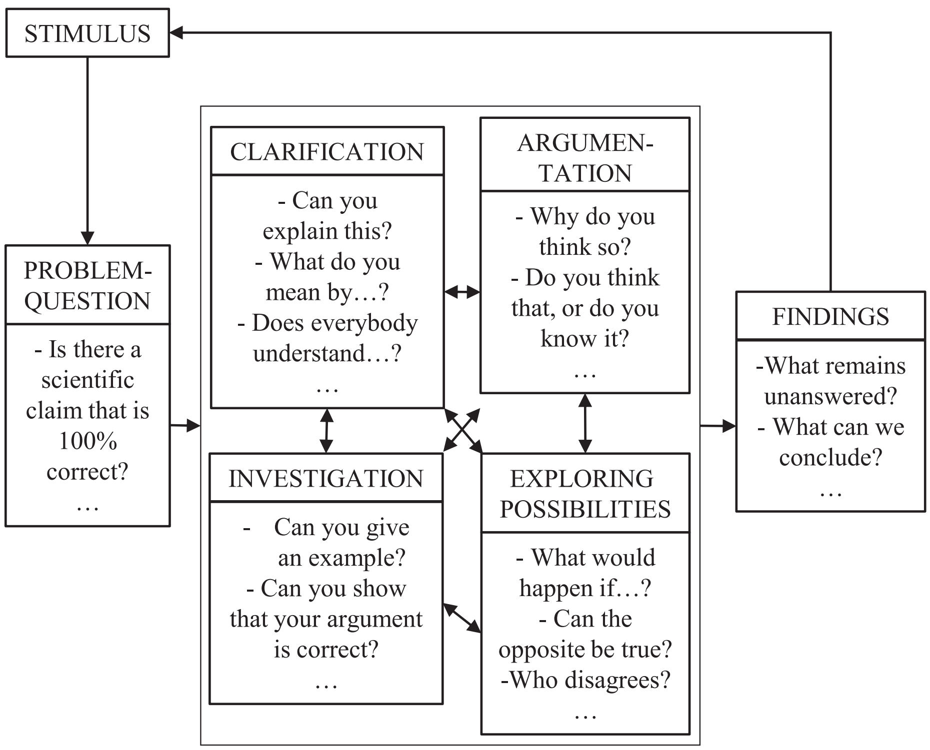
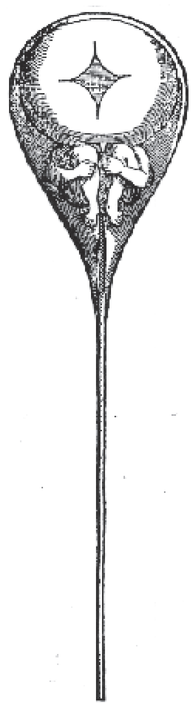


Figure 1: Distinct steps of the reflection method with examples of relevant questions

After probing the question, students explore possible or hypothetical answers. The teacher plays an important role during this exploration by asking different kind of questions. The aim of this dialogue is to explore the relevant assumptions and ideas of the students, in order to stimulate reflection about the NoS. The questions and the dialogue itself do not follow a strictly linear pattern (figure 2), but at least 4 categories can be distinguished.

1. Through questions such as 'What would happen if…?', or 'Can the opposite be true?' students are stimulated to explore different answers and hypotheses with regard to the central question.
2. Through questions such as 'What do you mean by…?', or 'Can you explain…?' students are stimulated to clarify the concepts they are using. Key concepts to be explored can entail the meanings of truth, science, interpretation, etc.
3. Through questions such as 'Why do you think so?' or 'Are you sure of this…?' students are stimulated to make arguments to buttress the answers they give. By asking for examples and by exploring the logical coherence of the arguments students explore and investigate the reliability of their arguments and answers.After the relevant ideas have been explored in the community of dialogue through different cycles of argumentation, clarification and investigation, the findings of the students can be listed.
4. The teacher can try to summarize the ideas, and tries to come to a conclusion. The findings will seldom have a final character: a new cycle of reflection can then start and the new list of questions becomes the beginning of a new investigation. It is also relevant to pose the following question by the end of a reflection cycle: 'Which questions are still on the table?'

This question stimulates students to get insight into the fact that science is not dominated by one certain method, and that different options are possible.



Facilitator: Can a scientist see without making an interpretation? (Problem)

Student 1: No, a scientist who sees a homunculus in a sperm cell shows that scientists are always interpreting and can never just see.

Facilitator: What do you mean with interpretation? Can you give a definition? (Clarification)

Student 1: Interpreting means that you explain what you see.

Facilitator: Does everyone agree that a scientist is always interpreting? (hypothesis formulation)

Student 2: I disagree. I think that only bad scientists don't make the difference between thinking and perceiving.

Facilitator: Why do you think so? (Argumentation)

Student 2: Because a scientist can only know something if he watches the world without prejudices.

Facilitator: Can you give an example? (Investigation)

Student 2: For a long time people thought that fossils were ancient monsters. Only by leaving the prejudice that there can be monsters, scientists were able to discover the truth about fossils.

Facilitator: Does everyone agree?

…

Figure 2: Example of a short philosophical dialogue elicited following the steps of the reflection model based on philosophical dialogue. The stimulus is the drawing by the 17th century Jan Hartsoeker of a sperm cell containing a small man, a homunculus.

RESEARCH DESIGN

To assess the applicability of the proposed method, a design-based research approach was followed (Plomp & Nieveen, 2007). This means that an initial didactical design is built up in collaboration with science education experts. In a second stage of the research the interventions are tested out in several classes through several cycles. After every cycle conclusions are drawn to improve the design of the intervention and to provide a (preliminary) assessment with regard to the impact of the approach. In a final stage the developed method is tested on a larger group of respondents, allowing for quantitative assessment.

In this study the initial didactical design was tested in two cycles on teacher students in pre-service training (bachelor degree in primary or secondary education). In the first cycle two classes of Belgian university colleges (UCLL and Vives) were involved. These classes had 8 and 41 students. The intervention consisted of a series of exercises aimed to elicit/bring forth students' insight in NoS. These exercises were:

- "Dressing up a scientist" – the students were asked what feature makes a scientist.

- “Dinosaur” – the students were presented with a picture of some bones and were asked to construct the dinosaur from which these bones originated. This led to a discussion on the tentativeness of science, the social and historical context in which science happens, the creativity which is needed in science, and the difference between interpretation and observation.
- “Wolves” – a movie fragment is shown where someone hears a sound in the woods and concludes that there are wolves around. This exercise also led to a discussion on the tentativeness of science and the subjectivity that is inherent in science.
- “Black box” – the students are presented with a sealed container and have to figure out what is inside (without opening the container). They formulate some hypotheses and perform basic experiments. They can however never know what is truly inside the container.

In the second cycle a total of three classes were involved. These classes came from three Belgian university colleges (Odisee, UCLL and Vives) and had 14, 8 and 26 students respectively. Again a series of exercises was used to teach involved students about NoS. These exercises included the first two exercises of the first cycle and one additional exercise.

- “Particles of matter” – Students are presented with different theories on the constituents of matter as they have been conceptualized over the course of history (ranging from models of Empedocles to work done at the LHC concerning the Higgs Boson). This exercise led to a discussion on the tentativeness of science, the social and historical context in which science happens, the creativity which is needed in science and the empirical nature of science.
- “Classification” – Students are presented with a number of beads (with different colours and different sizes, with and without holes), and are asked to classify them. This exercise leads to a discussion on the subjectivity which is present in science, the lack of roadmap to doing science and the therefore needed creativity.

RESULTS

Although the final research cycle is not yet completed (including the quantitative assessment), the already performed research cycles allow us to pinpoint some interesting observations concerning research questions 3 to 5.

Learning material

The use of questions and dialogue stimulates engagement and motivates students to keep looking for an answer. Two consecutive exercises tackling the same NoS issue, though, can lead to saturation among some students, decreasing their engagement. Exercises (the wolves) that do not allow students to connect with their existing knowledge of science were appreciated less by both students and teacher trainers.

Attitude of students and teacher trainers

Most students were engaged during the interventions because, as they reported, the presented approach was novel and encouraged them to think. One student reports: “*You learn to think, deeper and further than usual*.” Some students expressed frustration. “Blackbox” in particular was reported by many students as frustrating. A common remark on the post-intervention questionnaire was: “*It was unfortunate that the boxes could not be opened*.”

Most students feel they are, after an intervention of two hours, not yet prepared to teach NoS, nor do they feel prepared to use philosophical dialogue as a didactic tool. On the question ‘Do you have the feeling that you could teach NoS?” a student responded: “*Not yet. Maybe after a few sessions. I have to practice more on keeping the conversation going.*”

In the classes of pre-service secondary education teachers, male students were more engaged than female students. The discussions in all-male subgroups (the students were divided into smaller groups to work on specific assignments) were of a higher philosophical complexity than in the all-female subgroups.

Context variables

Some teacher educators reported that a frontal class configuration (i.e. where the teacher stands in front of rows of students) does not allow a fruitful discussion. A circular configuration, where the teacher sits in a circle together with the students, is experienced as allowing more discussion.

Background knowledge of both students and teacher has an impact on the quality of the dialogue and on the direction in which it goes. When the exercises used to initiate the NoS discussion (stimulus) are within the interests and closely tied to the background knowledge of the students, they were more engaged and able to draw from their background knowledge, enriching the discussion with apt examples. The facilitator (teacher trainer or student during assignments in smaller groups) must be able to follow the train of thought of the participants in the discussion group. Additionally, the facilitator must be able to steer the discussion in a direction interesting for NoS reflection. The presented didactic approach may not lead to the confirmation of misconceptions. Hence, experience and adequate background knowledge are necessary.

DISCUSSION

Introducing NoS in science education is challenging, but a challenge worth being undertaken in order to develop a deeper understanding of science in the new generation of citizens. In the study presented in this article, we have focused on an approach based on philosophical dialogue. This approach is currently being tested with the target group of pre-service teacher students for primary and secondary education. Our experience with the first research cycles has shown that the approach, meant to encourage discussion on NoS, really triggers students to think and engages them in fruitful discussions. A quantitative measure of gained NoS insight in students has not yet been performed, since this is the goal of the final research cycle which is now starting. Qualitative observation during the first cycles has pointed to a series of contextual factors appearing to enhance discussion on the specific NoS issue being considered. In particular, coupling between background knowledge of both students and teacher and the used stimulus, classroom configuration, and female-male differences have been identified as possible relevant external factors during the first phase of our tests. These should at the moment be considered only as first indications. Further research is needed to investigate new research questions arising from these observations.

Concerning the structure of the learning material used as NoS stimulus, our first results point to the choice of one more elaborate exercise over two smaller exercises as the most effective in inducing NoS reflection on a specific NoS aspect. Learning to lead a philosophical dialogue to achieve reflection on NoS is clearly not an easy task for teacher students. In order to allow transfer of the dialogic method from teacher training to the classroom, more practice in leading a philosophical dialogue is needed for students. Additionally, it is clear from our results that time is needed for students to develop insight in NoS.

We conclude that addressing NoS is necessary both in the classroom and in pre-service teacher training, and that in the latter enough time should be foreseen for students both for developing NoS insight and to master the needed dialogic techniques. However, it is important to stress that the link between NoS assignments and science must at all times be clear to students and pupils, in order to make sure that the discussions are experienced as a worthwhile lesson rather than a game or entertainment. Philosophical dialogue is an interesting and worthwhile addition to the classical attempts to teach about NoS. In fact, philosophical dialogue may be considered as a part of the practice of science, for instance when discussing hypotheses that can be tested, and its introduction in the science classroom allows for deeper science learning and literacy.

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