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CONCEPTIONS OF THE NATURE OF SCIENCE—ARE THEY GENERAL OR CONTEXT SPECIFIC?

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ABSTRACT. The study investigates the relationship between general and context-specific conceptions of the nature of science (NOS). The categorization scheme by Osborne et al. (J Res Sci Teach 40:692–720, 2003) served as the theoretical framework of the study. In the category *nature of scientific knowledge*, the certainty, development, simplicity, justification, and source of scientific knowledge were distinguished. In the category *methods of science*, the purpose of science and the creativity of scientists were mentioned. The study was conducted with 221 secondary school students, who filled in a 40-item questionnaire on general NOS conceptions. Furthermore, students were provided with different contexts by a short description of 10 scientific theories. After the theory introduction, students indicated context-specific conceptions as well as the importance and familiarity of each theory. Study results show that higher familiarity with scientific theories is related to a more informed view about the general nature of science. Correlational analyses illustrate that context-specific and general conceptions about NOS are not independent from each other but have a mutual core. Context-specific conceptions are not so different from their general counterparts that these aspects cannot be combined in a NOS questionnaire.

KEY WORDS: epistemological beliefs, general science, nature of science (NOS), secondary

INTRODUCTION

The nature of science (NOS) encompasses conceptions about scientific knowledge and knowing, values and beliefs incorporated in gaining scientific knowledge, as well as the influences of society, culture, and technology on science (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; Osborne, Collins, Ratcliffe, Millar & Duschl, 2003). Contemporary research on the nature of science focuses on the conceptions of differently aged students (Akerson & Hanuscin, 2007; Dogan & Abd-El-Khalick, 2008; Ibrahim, Buffler & Lubben, 2009; Khishfe, 2008; Lin, Chiu & Chou, 2004), pre-service science teachers (Abd-El-Khalick & Akerson, 2004, 2009; Akerson, Morrison & McDuffie, 2006; Hanuscin, Akerson & Phillipson-Mower, 2006; Lin & Chen, 2002; Liu & Lederman, 2007), and in-service science teachers (Akerson & Abd-El-Khalick, 2003; Dogan & Abd-El-Khalick, 2008; Irez, 2006; Southerland, Johnston & Sowell, 2006). As NOS conceptions are knowledge-based, they can be taught and learned (Abd-El-Khalick & Lederman, 2001; Khishfe, 2008). However, in all target groups, an insufficient or incomplete understanding of the nature of science can be found (e.g. Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Bianchini & Colburn, 2000; Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002). Especially secondary school students often know very little about the nature of science, and their conceptions of this topic are just beginning to emerge (Lederman, 2007). Therefore the question arises, on what basis do students judge the nature of science?

Perhaps students make use of a simple heuristic and base their judgment on the nature of science on the basis of a known theory. This can be, for instance, in the context of Darwin's selection theory. On the basis of knowledge about this theory, many central statements on the nature of science can be adequately answered: How certain is scientific knowledge? How can scientific knowledge be justified? Do ideas in science sometimes change? Is creativity needed to develop scientific theories? Students who judge on the basis of knowledge about Darwin's selection theory will rate scientific knowledge as rather certain, but not absolutely. They know that Darwin's observations of the Galapagos finches and countless other research results justify but cannot prove selection theory. They also know about Lamarck's competing theoretical conception and can derive from this that scientific ideas sometimes change (van Dijk & Reydon, 2010). Furthermore, they can recognize Darwin's combination of different facts and findings about the evolution of species as a highly creative achievement. Hence, students have the opportunity to judge fundamental questions about the nature of science on the basis of knowledge of just one theory—the selection theory. However, do students judge in this way?

In contrast to this position that students base their knowledge about NOS on one theory alone, it can be assumed that *general* opinions and convictions about NOS are dominant. Therefore, students' general conceptions about the nature of science should be reflected in learning involving the judgment of diverse scientific contexts. In a questionnaire study with secondary school students, we thus concentrated on this particular relationship between general and context-specific views on the nature of science. The aim of our research was to find out more about students' context-specific conceptions of the nature of science. These context-specific conceptions manifest themselves in their epistemological convictions about scientific theories. Potentially, they are an important source that students can use to construct general judgments about NOS.

The Views of Nature of Science Questionnaire (VNOS) by Lederman et al. (2002) is the most often used instrument for assessing NOS conceptions. In the long form, VNOS-C, the questionnaire contains general as well as context-specific questions about NOS. On the one hand, participants are asked to answer global questions about their view of science or the status of experiments. On the other hand, interviewees are confronted with specific questions about the extinction of dinosaurs, the certainty of atom theory, or the definition of a species. Are those generally and context-specific elicited conceptions related to each other or do they belong to different dimensions? A closer look at the connection between general and context-specific NOS conceptions can also give important information about this question, which might be another advantage of this research study.

The research questions that guided the study on context-specific and general NOS conceptions were: (1) Does a higher level of familiarity with scientific theories lead to more accurate judgments about the general nature of science? The first question can reveal if single scientific theories are an adequate starting point to learn more about the general nature of science. (2) What is the relationship between context-specific and general views about the nature of science? The second question can show if context-specific and general NOS views can be combined in a measuring instrument.

Theoretical Background

In order to determine the general and context-specific conceptions to be compared with each other, it is necessary to focus on certain dimensions of the nature of science. The following search after core dimensions of NOS is guided by the question about which concepts students are to be informed.

The development of an adequate understanding of the nature of science is a widely recognized aim of science education (American Association for the Advancement of Science, 1990; National Research Council, 1996). Students should learn about the purpose of science, how scientific knowledge is obtained, and which values and beliefs influence the advancement of scientific knowledge (Abd-El-Khalick & Lederman, 2001; Lederman, 1992). In relation to a more detailed description of NOS, it is often stated that scientific knowledge has a tentative character, develops over time, is based on empirical evidence, is derived from observations and experiments, has subjective parts and is theory-laden, is a product of human creativity, and is affected by social, cultural, and technological circumstances (Abd-El-Khalick, 2006; McComas & Olson, 1998; Osborne et al., 2003). Moreover, the crucial distinction between observations and inferences, the functions and relations of scientific theories and laws, and the myth of only one scientific method, likened to a cooking recipe, are considered as important aspects of NOS (Abd-El-Khalick, Waters & Le, 2008; Lederman et al., 2002).

The question of what students should learn about NOS cannot be answered by a single person but has to be discussed and clarified by different people on an intersubjective level. Opinions and convictions of experts and institutions must be gathered, compared, and combined into a product. McComas & Olson (1998) and the research group of Osborne (Osborne et al., 2003) collected such intersubjective perceptions of NOS.

McComas & Olson (1998) analyzed eight national education standards and curricula related to scientific subjects. They could show that fundamental elements of NOS that appear in the US education standards (American Association for the Advancement of Science, 1993; National Research Council, 1996) can also be found in the national science documents of Australia, New Zealand, Canada, England, and Wales. McComas & Olson (1998) list altogether 14 common opinions on the nature of science, which cannot be described here in every detail. They highlighted science as the attempt to explain natural phenomena. Scientific knowledge is not only gained by one universal method. It rests upon observations, experimental evidence, and rational argumentation and has a relatively durable but tentative character. Scientists are creative and people from all cultures can contribute to scientific knowledge. Science is influenced by new technology as well as social, historical, and cultural circumstances. Taken together, it means that on the level of educational policy, converging opinions definitely exist about core elements of NOS.

Osborne et al. (2003) selected the Delphi method to approach the nature of science. Science experts from different fields were asked independently in a multi-stage procedure about the ideas that should be taught in school science. The 23 international experts were involved in the fields of science, science education, history, philosophy, and sociology of science as well as science journalism and school science. In three consecutive rounds, expert opinions about the nature of science were gathered and reported back to the participants. The feedback about the statements of the other participants was expected to stimulate the reflection and modification of personal views in order to arrive at valid opinions on core dimensions of NOS.

The study results of Osborne et al. (2003) showed that the science experts finally arrived at very similar conclusions to McComas & Olson (1998) in their analysis of national standard documents. Osborne et al. (2003) distinguished in their article between three major categories of NOS. In the category *nature of scientific knowledge*, they emphasize, in accordance with McComas & Olson (1998), the tentativeness, uncertainty, changeability, and empirical character of scientific knowledge. In the category *methods of science*, one significant concept mentioned (in parallel with national education documents) is that no universal method exists for gaining scientific knowledge. Moreover, in the category *institutions and social practices in science*, Osborne et al. (2003) and McComas & Olson (1998) arrived at the conclusion that science is influenced by social, technological, and historical circumstances. Taken together, these results mean that not only educational administrators but also scientists, science educators, philosophers, and practitioners of science could reach a consensus on the basic concepts of NOS.

In the following, the core dimensions of NOS that are more precisely described form the theoretical basis of our investigation. The presentation concentrates on the categories *nature of scientific knowledge*, *methods of science*, and *institutions and social practices in science* according to Osborne et al. (2003). This classification is meaningful but does not always distinguish accurately. For example, scientific methods as observations and experiments are used to justify scientific knowledge. Conversely, scientist's content knowledge influences the selection of an appropriate scientific method.

Firstly, the category *nature of scientific knowledge* should be focused upon. Here parallels arise between research on NOS and investigations on epistemological beliefs in science (Conley, Pintrich, Vekiri & Harrison, 2004; Elder, 2002). Domain-specific epistemological beliefs are an important part of understanding the nature of science. In accordance with the general theoretical conception of epistemological beliefs by Hofer & Pintrich (1997) and later science-oriented investigations by Elder (2002) and Conley et al. (2004), the certainty, development, simplicity, justification, and source of scientific knowledge can be presented as core dimensions.

Certainty of Knowledge. Although scientific knowledge is relatively reliable and durable, it is never absolute and totally certain. Existing theories and concepts should be regarded as tentative. New knowledge can always be added to even very intensively researched topics. Also different theories which explain the same phenomenon can be accepted as true as long as no other evidence argues against it. Likewise, it is a mistake to believe that all scientific problems have only one solution (Bartholomew, Osborne & Ratcliffe, 2004; Chen, 2006; Lederman et al., 2002; McComas, Almazroa & Clough, 1998; Osborne et al., 2003).

Development of Knowledge. Scientific knowledge supports a continuing developmental process. Scientific theories and concepts can permanently change and be extended on the basis of new evidence. Changing knowledge is, for example, promoted by new technologies that offer better research facilities. This change is, however, not accompanied by anything approaching an absolute truth. The history of science underscores the evolutionary and revolutionary character of the domain (McComas & Olson, 1998; Osborne et al., 2003; Tobin & Robbie, 1997).

Simplicity of Knowledge. Scientific knowledge is constructed with a tendency to simplify without denying the complexity of natural phenomena. In science, there is a continuous striving to explain, preferably a large number of observations, with the lowest possible number of concepts. This principle was stated first by William of Occam in the fourteenth century. Scientific phenomena should be explained in the most economical way possible. Therefore, it is a misconception when students believe that of two theories, which explain a phenomenon equally well, the more complex theory is the better one. Scientific theories are formulated rather more generally and comprehensively than specifically and in detail (Hofer, 2000; Hofer & Pintrich, 1997; Rubba & Andersen, 1978).

Justification of Knowledge. Scientific knowledge relies on observations, experiments, rational arguments, and skepticism. Students should learn to distinguish between observations and inferences. Experiments can be seen as an appropriate way to justify scientific knowledge. Experimental data can support one's own beliefs and show whether a prediction proves to be convincing (McComas & Olson, 1998; Osborne et al., 2003).

Source of Knowledge. Scientific knowledge is not solely presented by omniscient authorities but can also be discovered and acquired by learners themselves. Learners can believe much, but should not uncritically believe everything, of what can be read in science textbooks or is stated by scientists. This knowledge has a tentative character and is subject to change, including the fact that people from all cultures can contribute their ideas to the scientific knowledge pool (Elder, 2002; McComas & Olson, 1998).

In the category *methods of science*, there are four further core dimensions that characterize the nature of science. These dimensions are the purpose of science, the distinction between theories and laws, the myth of the one, cooking recipe like scientific method, and the creativity and imagination of scientists.

Purpose of Science. Science is the attempt to describe, explain, and predict natural phenomena. Through science, the experiences of humankind with animate and inanimate nature can be explained. In the foreground of knowledge construction is the search for explanations, the prediction of natural phenomena, and the solution of scientific problems (Driver, Leach, Millar & Scott, 1996; Labudde, 2000; McComas & Olson, 1998).

Theories and Laws. In science, theories and laws serve different functions. Scientific theories are highly respected, well trusted, and in themselves consistent explanatory systems. Predictions can be derived from them and tested by observable facts. Laws formally describe the relations between observable phenomena. Laws do not possess a higher rank than theories, as some students believe. Theories can also not be converted into laws by frequent proof. Moreover, laws and theories constitute different products of science (Lederman et al., 2002; McComas & Olson, 1998).

Scientific Method. A prevalent, but false student opinion is the assumption of only one correct scientific method. Although scientists frequently state hypotheses, plan experiments, collect data, and draw conclusions, it is not the only method that leads to reliable results. In fact, there is no prescribed sequence of research steps or a strictly determined way to solve problems. Scientific problems can be solved by different methods, and the selection of a successful method is determined by the conditions (Lederman et al., 2002; McComas & Olson, 1998; Osborne et al., 2003).

Creativity and Imagination. Contrary to common beliefs, the production of scientific knowledge is not a perfectly rational and absolutely logical process. Moreover, the development of scientific knowledge requires a scientist's creativity and imagination. This is valid for all research processes, from finding research ideas to analyzing and interpreting data.

Some scientific concepts are based on enormous intellectual performances, which would not have been possible without the inspiration and imaginative power of scientists (Bartholomew et al., 2004; McComas & Olson, 1998; Osborne et al., 2003).

In the category *institutions and social practices in science*, one can find very heterogeneous opinions about core dimensions. The dimension *social and cultural influences on science*, however, is recognized by many researchers.

Social and Cultural Influences on Science. Science is conducted in a cultural context in which researchers are inevitably intertwined. They, as well as learners, must be aware that the application of scientific knowledge does not occur value-free, but can be in conflict with the moral and ethical values of social groups. Equally important, learners should experience the fact that scientific research, like mapping and sequencing the human genome, is often carried out by multidisciplinary, international research groups. Cooperation and collaboration among scientists promote the development of scientific knowledge (Lederman et al., 2002; McComas & Olson, 1998; Osborne et al., 2003).

Altogether, ten core dimensions of the nature of science can be identified. The core dimensions are characterized by the fact that they are based on a broad consensus of opinions and this should be conveyed in science lessons.

Hypotheses

A prior study by Trautwein & Lüdtke (2007a) has analyzed the association between topic-specific and global beliefs for the certainty dimension. Ten theories from science, medicine, and psychology were used in this study to stimulate topic-specific thinking. The authors found a significant but only small relation between topic-specific and global beliefs. Furthermore, they detected considerable differences in students' familiarity with different theories and the assigned certainty of theories.

In our study, we wanted to test if students judge on the basis of single known theories about the nature of science. The first hypothesis argues that higher familiarity with scientific theories leads to more accurate judgments about the general nature of science. The reason for this assumption is that if students know a scientific theory well, they have more options to generalize their NOS knowledge. Higher familiarity with theories would thus enable them to make judgments more appropriately about the general character of NOS. The first hypothesis is further corroborated by a study on college students' development of representations about the nature of theories in an astronomy course (Dagher, Brickhouse, Shipman & Letts, 2004). After a semester of deliberate instruction about the nature of astronomy theories, students were slightly more able to reason about NOS. Our second hypothesis stated that students build context-specific rather than general judgments about NOS. It is easier for younger students to derive knowledge about NOS from a single scientific theory than to reflect on science as a whole. In this case, dependent on the concrete theory, relations between context-specific and general conceptions about NOS should be able to be detected in the data. For theories, which students do not regard as important or with which they are not familiar, non-significant correlations should be found. For important or familiar theories, however, significant correlations between context-specific and general NOS conceptions should occur.

Method

Sample

The study was conducted with 221 secondary school students whose average age was 14.69 years (SD = 0.97). Students were selected from four different above-average schools with a strong emphasis on education but no specialization in science. Students' science education can be regarded as typical for students of their age and school career. The proportion of female participants in the sample was higher (79%) because 108 students came from a female-only school. We decided to use the other half of the sample (47 boys and 66 girls) to be a control in order to test if the deployed questionnaire was gender fair. None of the mean comparisons on general conceptions about the nature of science became significant, which means that boys and girls held similar conceptions.

Material

General Conceptions. A 40-item questionnaire was used to measure general conceptions of the nature of science by five-point rating scales (1—"absolutely not true", 2—"somewhat true", 3—"partly true", 4—"rather true", 5—"absolutely true"). The questionnaire with its seven scales was developed on the basis of the aforementioned core dimensions. Well-known questionnaires on the nature of science (Chen, 2006; Kang, Scharmann & Noh, 2005; Labudde, 2000; Leach, Millar, Ryder & Séré, 2000; Lederman et al., 2002; Lin et al., 2004; Priemer, 2003; Rubba & Andersen, 1978; Solomon, Scott & Duveen, 1996) and on epistemological beliefs (Buehl, Alexander & Murphy, 2002; Conley et al., 2004; Hofer, 2000; Ryan, 1984; Schommer, 1998; Schraw, Bendixen & Dunkle, 2002; Stathopoulou & Vosniadou, 2007; Trautwein & Lüdtke, 2007b; Wood & Kardash, 2002) were used for item generation. In an initial investigation with secondary school students, the newly developed instrument showed a sufficient internal consistency (Cronbach's $\alpha = 0.84$). It permitted the measurement of general conceptions about the certainty, development, justification, simplicity, and source of scientific knowledge and, in addition, allowed the obtaining of assumptions about the purpose of science and the creativity of scientists (Urhahne, Kremer & Mayer, 2008; Kremer, Urhahne & Mayer, 2008). The conviction that in science only one correct method exists could be assigned to the dimension *certainty* by means of factor analysis. The remaining core dimensions *theories and laws* and *social and cultural influences* were excluded during the process of questionnaire development because these concepts are still difficult to grasp for secondary school students. The full version of the NOS questionnaire can be retrieved from the Internet (http://www.psy.lmu.de/excellence/personen/director/urhahne/download/index.html). Item examples for the seven scales are given in Table 1. The reliability of the scales is typical for measuring epistemological beliefs, as Muis, Bendixen & Härle (2006) have pointed out in a review article. Furthermore, correlations to grades, domain-specific self-concepts, and a knowledge test were calculated in order to check the external validity of the questionnaire. Findings on the validity of the questionnaire are reported in the "Results" section.

Context-Specific Conceptions. Ten scientific theories from the secondary school science curriculum were selected to measure context-specific conceptions. Every theory was described as shortly as possible, by three to four sentences. Longer, more precise theoretical explanations might be found annoying and would not have been read by the students. Translated descriptions of the science theories are given in Table 2. The theories varied considerably in their explanatory scope, but had in common that they described a natural phenomenon and provided a possible explanation for its occurrence. It was indicated that all theories, even though some were created to explain historic events, were still of relevance (e.g. that even today species become extinct by changes of the environment or that continental drift is a cause for the development of earthquakes). Students rated the importance of each theory to their lives and their familiarity with the theory on five-point Likert scales. Afterwards, they expressed their context-specific conceptions of the nature of science by ten items as shown in Table 3. The items were chosen in a way that one or two core statements represented each NOS dimension. Again, five-point Likert scales were used for appraisal of context-specific conceptions.

Science Grades. Students were asked for their last grades in biology, chemistry, and physics. Grades ranged from 1—"very good" to 5—"insufficient". Students received better grades in biology (M = 2.55, SD = 0.77) than in chemistry (M = 2.72, SD = 0.93) or physics (M = 2.97, SD = 0.91). Grades for biology, chemistry, and physics were z-transformed due to mean differences and combined into a common science grade for each student.

Domain-Specific Self-Concepts. Students' academic self-concepts for biology (Cronbach's α = 0.80) and physics (Cronbach's α = 0.85) were assessed by five items for each. An item example is: "Biology/physics is easy to understand." By asking for domain-specific self-concepts in biology and physics, the poles of ability for practicing and understanding science could be assessed. All students had sufficient experience with biology and physics lessons to make reliable judgments. Students clearly

TABLE 1

Seven general dimensions of the nature of science

Scale	*Item example*	*Items*	*Cronbach's α*
Source	Only scientists can think over scientific research questions (–)	5	0.56
Certainty	Once scientists get a result from an experiment there is only one solution (–)	5	0.61
Development	New findings might change what scientists hold as true	7	0.69
Justification	It is important to conduct experiments more than once to support results	9	0.62
Simplicity	Scientific theories are often more complicated than they have to be (–)	4	0.52
Purpose	The goal of scientific theories is to explain natural processes	4	0.53
Creativity	Scientific knowledge shows the creativity of scientists	6	0.65
Total		40	0.81

(–) Reverse coded item

TABLE 2

Description of ten scientific theories to evoke students' context-specific conceptions about the nature of science

Scientific theory	*Description*
Climate change	Car and industrial exhaust gases change the composition of the atmosphere. In this way, our climate warms up, glaciers melt, and the sea level rises. It leads to an increase in high water levels, violent storms, and heat waves
Evolution	Organisms demonstrate adjustment to the environmental conditions of their habitat. Those organisms, which are adapted best to the environmental conditions, can reproduce themselves most frequently and thus pass on hereditary characteristics particularly successful to the next generation. This adjustment process constantly continues in nature
Smoking	Smoke increases the danger of cancerous diseases, particularly within the area of the respiratory system. The cigarette smoke contains ingredients, which cause the rampant growth of cells. There is also passive smoking: thus, the inhalation of tobacco smoke increases the lung cancer risk of non-smokers
Aggression	Media consumption influences the behavior of children and young developing people. Seeing demonstrations of violence, which are consumed and accumulated over a longer period, lead to habituation. In this way, the readiness of young people to react violently to controversies or discrepancies in their circle of friends increases
Intelligence	The intelligence of individuals is to a large part inherited from their parents. The number of the nerve cells and the structure of the brain are determined by heredity. Inherited intelligence forms the basis for all learning at school and in further life
Dinosaurs	If the environmental conditions change, an extinction of species may follow. The extinction of the dinosaurs was caused by the impact of large meteorites approximately 65 Ma ago. As a result of the impact, the atmosphere was darkened by the whirled up dust, and the climate cooled down, whereby the dinosaurs became extinct. Also today, species become extinct by modifications in the environment
Continental drift	Billions of years ago, there was on Earth only one primordial continent, which was surrounded by seawater. At that time, there was a fragmentation of this primordial continent and by drifting apart the fragments formed the continents, which we know today. By continuing these shifts, it results in earthquakes in other sections of the earth
Big Bang	The universe was born approximately 10–12 billion years ago from a Big Bang. Since the Big Bang, the universe expands evenly. Its temperature and density constantly decrease. This process is still continuing

TABLE 2

(continued)

Scientific theory	*Description*
Out of Africa	The origin of mankind is situated in Africa. These primordial men in Africa left the continent approximately 1.8 Ma ago to establish elsewhere and developed into modern humans. All living humans today thus descend from an original group from Africa
Mobile phone	Rays, as they are sent by mobile phones, can endanger health. Through radiation, there is a modification of the genetic material in the cells. In this way, carrying mobile phones in body proximity and long telephoning increase the risk to get sick with cancer and allergies

possessed a higher self-concept in biology ($M = 3.81$, SD = 0.84) than in physics ($M = 3.36$, SD = 0.99; $t = 5.81$, $df = 196$, $p < 0.001$).

Science Terms Knowledge Test. In addition to NOS questionnaires, students were asked to explain different science terms by means of multiple-choice and open-ended questions. The following items were used: (1) What is a scientific theory? (2a) Do scientists use their creativity in investigations? (2b) Explain your answer! (3a) What is an experiment? (3b) Name the features of an experiment! Every correct answer to a single

TABLE 3

Ten items to measure context-specific conceptions about the nature of science

Item	*Dimension*
1. Even non-scientists can contribute to the development of this theory	Source
2. Only this theory can adequately explain the described processes (–)	Certainty
3. This theory will forever be true (–)	Certainty
4. New findings might change this theory	Development
5. There is only one way to test this theory (–)	Justification
6. Further research is needed to support this theory	Justification
7. This theory is more complicated than it had to be (–)	Simplicity
8. Goal of this theory is to predict processes in nature	Purpose
9. Goal of this theory is to explain processes in nature	Purpose
10. Scientists had to be creative for developing this theory	Creativity

(–) Reverse coded item

question was graded with one point. For example, the control of conditions and variation of variables had to be both listed as features of an experiment in order to receive a full point. On average, students answered nearly three of the five items correctly (M = 2.91, SD = 1.40).

Procedure

In the presence of their science teachers, students filled in a 15-page questionnaire during regular biology classes. The questionnaire contained some sociodemographic questions and the items and scales described above. Students worked independently on the questionnaires. The whole investigation lasted about 45 min.

Results

As a first step, the validity of the general questionnaire on the nature of science was analyzed. Better science students were assumed to have higher NOS understandings. Therefore, external criteria like science grades, knowledge of science terms, and self-concept of science ability should at least partly overlap with knowledge about the nature of science. In order to test this assumption, correlations between the validity criteria and the seven measured dimensions of NOS were calculated. The results are depicted in Table 4. It can be shown that results on all four criteria met the expectations. Students with better grades, a higher self-concept in

TABLE 4

Correlations between general NOS dimensions and science grades, self-concepts of ability, and science terms knowledge test

Dimension	*Science grades*	*Self-concept biology*	*Self-concept physics*	*Science terms knowledge test*
Source	−0.10	0.10	0.23**	0.17*
Certainty	−0.18**	0.18**	0.25***	0.33***
Development	−0.17*	0.19**	0.17*	0.27***
Justification	−0.19**	0.20**	0.23**	0.19**
Simplicity	−0.32***	0.22**	0.33***	0.21**
Purpose	−0.03	0.12	0.10	0.21**
Creativity	−0.02	0.04	−0.02	0.31**

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

biology, respectively, physics and more scientific knowledge showed a more sophisticated understanding of NOS.

Regarding context-specific conceptions, we asked how important students considered the described theories for their personal life and how much they knew about them. Table 5 shows a clear result: Scientific theories that had a strong relevance to students' lives were regarded as much more important. The influence of smoking on the formation of cancer cells was judged as the most important theory. The theory that humankind had its offspring in Africa and Darwin's selection theory were regarded as relatively unimportant for students' current lives. Moreover, it became clear that theories that were regarded as important were much more familiar to the students. Only the theory about the inheritance of intelligence was an exception because the familiarity ratings for this theory were relatively low. Other theories on smoking, climate change, aggression resulting from exaggerated media consumption, and radiation of mobile phones, however, possessed the highest familiarity values.

In order to test our first hypothesis that higher familiarity with scientific theories leads to more exact judgments about the general nature of science, correlations between familiarity ratings and NOS dimensions were computed for each theory. As can be seen in Table 6, only the theories that students were familiar with showed significant correlations with general NOS dimensions. The last column in Table 6 presents the average correlation across the different dimensions. In order to achieve this value, correlations of each theory were transformed into Fisher

TABLE 5

Means and standard deviations for importance and familiarity of ten scientific theories

	Importance		*Familiarity*	
Scientific theory	*M*	*SD*	*M*	*SD*
Smoking	3.74	1.14	3.96	1.03
Mobile phone	3.27	1.11	3.28	1.14
Climate change	3.19	1.09	3.59	0.99
Aggression	3.13	1.11	3.56	1.20
Intelligence	3.01	1.13	2.78	1.10
Dinosaurs	2.78	1.15	3.19	1.12
Continental drift	2.68	1.18	3.24	1.25
Big Bang	2.48	1.10	2.33	1.16
Out of Africa	2.33	1.01	2.45	1.29
Evolution	2.32	0.97	2.98	1.11

TABLE 6

Correlations between familiarity with scientific theories and general NOS dimensions

Rank	*Scientific theory*	*Source*	*Certainty*	*Development*	*Justification*	*Simplicity*	*Purpose*	*Creativity*	*Mean r*
1	Smoking	0.19**	0.15*	0.22**	0.30***	−0.11	0.27***	0.09	0.16*
2	Climate change	0.08	−0.06	0.25***	0.27***	−0.11	0.24***	0.09	0.11
3	Aggression	0.29***	0.25***	0.24***	0.27***	0.03	0.22***	0.07	0.20**
4	Mobile phone	−0.00	−0.02	−0.02	−0.03	−0.14*	−0.01	0.02	0.03
5	Continental drift	0.06	0.27***	0.30***	0.26***	0.09	0.25***	0.05	0.18**
6	Dinosaurs	0.07	0.17*	0.12	0.12	0.02	0.16*	−0.02	0.09
7	Evolution	−0.02	0.01	0.01	0.09	0.02	0.01	−0.06	0.01
8	Intelligence	0.04	−0.07	−0.05	−0.04	−0.04	−0.06	0.03	−0.02
9	Out of Africa	−0.07	0.06	0.05	0.04	0.06	−0.12	0.00	0.00
10	Big Bang	0.00	−0.09	−0.04	−0.04	0.08	−0.06	−0.05	−0.03

$*p < 0.05$; $**p < 0.01$; $***p < 0.001$

z-values and a mean Fisher z-correlation was built. The Fisher z-correlation was retransformed into a Pearson correlation. Three mean correlations of the most familiar theories became significant (smoking, aggression, and continental drift). The correlation between the familiarity rank of the theories on the most left side and the mean correlation on the most right side of Table 6 amounts to $r = -0.79$ ($p < 0.01$). This means that with higher familiarity of scientific theories, higher correlations between familiarity and general conceptions about NOS occurred. Even though most of the correlations in Table 6 are low, supporting evidence for the first hypothesis of the investigation could be identified: Familiarity with scientific theories goes along with more adequate conceptions about the general NOS.

The second hypothesis claimed that students judge more context specifically than generally about the nature of science. In order to test this hypothesis, correlations between context-specific and corresponding general conceptions of NOS were computed. The correlations were calculated in this way so that the one or two judgments about a dimension for a certain theory were correlated with the analogous general NOS dimension measured by a scale with several items. The results of this procedure are shown in Table 7. Significant correlations between context-specific and corresponding general NOS conceptions can be detected for all scientific theories. Continuously significant correlations with general conceptions could be found for the Big Bang, dinosaur, and evolution theory, but also other theories displayed substantial correlations.

Discussion

Learning about the nature of science is recognized as an important educational aim. It is still an open question, however, as to how this aim could be achieved. It might be helpful to approach the nature of science by contextual learning about single scientific theories (McComas, 2008). Learners can experience, on the basis of formation of a theory, that scientific knowledge is tentative and developing, is striving for simplicity, and is justified by observations and experiments. Learners can acknowledge the creativity and imaginative power of scientists during the process of theory formation and gain insight on the purpose of science. In dealing with a theory, learners can develop their own points for consideration and view the theory in a different light.

All these NOS aspects were investigated in detail in a questionnaire study with secondary school students. It appears that, according to the

TABLE 7

Correlations between context-specific and corresponding general conceptions of the nature of science

	Source	*Certainty*	*Development*	*Justification*	*Simplicity*	*Purpose*	*Creativity*
Smoking	0.36***	0.04	0.08	0.01	0.16*	0.05	0.14
Mobile phone	0.21**	0.30***	0.34***	0.31***	0.02	0.08	0.02
Climate change	0.28***	0.36***	0.12	0.25***	0.21***	0.30**	0.29**
Aggression	0.35***	0.15*	0.30***	0.26***	0.17*	0.07	0.15*
Intelligence	0.21**	0.32***	0.43***	0.30***	0.30***	0.10	0.37***
Dinosaurs	0.19**	0.23**	0.23**	0.18**	0.31***	0.35***	0.27***
Continental drift	0.12	0.06	0.18**	0.26***	0.27***	0.40***	0.28***
Big Bang	0.20**	0.30***	0.23**	0.36***	0.35***	0.35***	0.31***
Out of Africa	0.15*	0.17*	0.16*	0.05	0.27***	0.07	0.26***
Evolution	0.18**	0.20**	0.23**	0.16*	0.27***	0.34***	0.28***

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

first hypothesis, higher familiarity with scientific theories is accompanied by more informed NOS conceptions. This means that options exist to derive general conclusions about NOS based on the knowledge of just one theory. Students can apply their theoretical knowledge to make statements that reflect sophisticated NOS positions. Conflicting theories like climate change or the impact of mobile phones on people's health can function as catalysts to quickly learn about how science works in reality. When students derive the concept from these theories that scientific knowledge is not as certain as it seems to be and needs to be justified, they have immediately understood important parts of NOS. However, the correlations between familiarity ratings and general NOS conceptions were not as high. Therefore, this plausible explanation as to how students develop an understanding about science represents only one way for attaining adequate positions on NOS.

This conclusion is also suggested by the results for the second hypothesis. It was hypothesized that higher correlations between context-specific and general NOS conceptions occur according to the importance or familiarity of a scientific theory. This assumption, however, cannot be supported by the empirical data. Rather, it can be stated that context-specific and general NOS conceptions considerably overlap for all investigated theories, even for those that were not regarded as important or familiar. Yet how can students generalize knowledge about a theory they have never heard of? It does not make sense to assume that even conceptions about unknown scientific theories can be transferred into correct general statements. Thus, it is more plausible to claim that global NOS conceptions were generalized to conceptions about different scientific theories. This assumption can much better explain why context-specific and general conceptions correlated significantly in every case in our study.

In the introduction, we stated that the VNOS questionnaire by Lederman et al. (2002) mixed general and context-specific NOS conceptions. It might be possible that these conceptions tap different levels of NOS and have to be analyzed separately. The correlations in our study, however, illustrated a common core of general and context-specific conceptions, which can be measured independently from a concrete theory. Context-specific conceptions are not so different from their general counterparts that a combination of these aspects in a questionnaire would lead to a dramatic distortion of the research results.

It is still an unresolved issue as to how students learn to judge about the nature of science. A questionnaire study can only give some initial clues about which type of information students used. For further elaboration, quasi-experimental studies would be necessary to decipher the psychological mechanisms behind understanding the nature of science. The present research findings fuel the speculation that learning about the history of science can be considered as helpful to understand the nature of science as well.

In the literature, some excellent examples already exist of how a research study, which makes use of a historical approach, should be constructed. Irwin (2000) integrated the development of atomic theory from the ancient Greeks to the present, into science lessons for secondary school students. Dagher et al. (2004) accompanied college students who, during the semester, learned about the nature of science by studying astronomical theories. Howe & Rudge (2005) and Rudge & Howe (2009) developed lesson plans to teach students the history of research on sickle-cell anemia by an explicit and reflective approach. Mamlok-Naaman, Ben-Zvi, Hofstein, Menis & Erduran (2005) developed a teaching module in order to promote tenth graders' understanding of the structure of matter and chemical reactions. Kim & Irving (2010) utilized the history of science in genetics to advance students' understanding of the nature of science. Moreover, McComas (2008) listed 80 historical examples from popular books about the nature of science that can be used as a resource of instruction.

Research clearly shows, however, that transfer of NOS knowledge does not happen automatically. Students do not learn relevant NOS aspects through historical examples alone or by instruction that refers only casually to elements of the nature of science. Several researchers have pointed out that complex NOS ideas should be accompanied by explicit and reflective discussion of the underlying concepts and principles (Clough, 2006; Khishfe & Abd-El-Khalick, 2002; Lederman, 2007). To assume that learning of NOS can be achieved just by giving students systematic input on a topic has turned out to be an incorrect belief (McComas, 2008).

All in all, studying the relationship between context-specific and general NOS conceptions has emerged as a fruitful research topic. Students who were more familiar with scientific theories could more easily abstract and transfer context-specific knowledge to central NOS aspects. However, more quasi-experimental investigations in school should deal with the question of whether NOS can be learned via instruction (cf. Khishfe, 2008). Thereby, it could be more exactly determined as to whether the provision of context-specific information would lead students to more sophisticated general conceptions of the nature of science or if teaching general NOS information would be a better starting point.

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