

# Nature of Science and Science Content Learning

## The Relation Between Students' Nature of Science Understanding and Their Learning About the Concept of Energy

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**Abstract** Besides viewing knowledge about the nature of science (NOS) as important for its own value with respect to scientific literacy, an adequate understanding of NOS is expected to improve science content learning by fostering the ability to interrelate scientific concepts and, thus, coherently acquire scientific content knowledge. However, there is a lack of systematic investigations, which clarify the relations between NOS and science content learning. In this paper, we present the results of a study, conducted to investigate how NOS understanding relates to students' acquisition of a proper understanding of the concept of energy. A total of 82 sixth and seventh grade students received an instructional unit on energy, with 41 of them receiving generic NOS instruction beforehand. This NOS instruction, however, did not result in students having higher scores on the NOS instrument. Thus, correlational analyses were performed to investigate how students' NOS understanding prior to the energy unit related to their learning about science content. Results show that a more adequate understanding of NOS might relate to students' perspective on the concept of energy and might support them in understanding the nature of energy as a theoretical concept. Students with higher NOS understanding, for example, seemed to be more capable of learning how to relate the different energy forms to each other and to justify why they can be subsumed under the term of energy. Further, we found that NOS understanding may also be related to students' approach toward energy degradation—a concept that can be difficult for students to master—while it does not seem to have a substantive impact on students' learning gain regarding energy forms, transformation, or conservation.

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## 1 Introduction

Nature of science (NOS) has long been promoted as an important content of science education (Lederman 2007; Lederman and Lederman 2014; Schulz 2014) and has consequently been included in multiple standard documents worldwide (McComas and Olson 1998; e.g., NGSS Lead States 2013). As early as about 20 years ago,<sup>1</sup> Driver et al. (1996) provided five arguments for an inclusion of NOS in science teaching. Besides outlining the inherent value of NOS for dealing with science-related issues and discussions in everyday life, Driver and colleagues also suggested a functional value of NOS, claiming that it would support successful learning of science content. All arguments seem very reasonable from a theoretical point of view; yet, there is only little to no empirical evidence about their validity (Lederman 2007; Lederman and Lederman 2014; Peters 2012). At the same time, Schulz (2014), for instance, argues that science education should also cover epistemic goals like conveying adequate ideas about knowledge, truth, and justification—goals for which NOS understanding seems to be an important prerequisite. Teixeira et al. (2012) provide a synthesis of studies that focus at these goals, using aspects of history and philosophy of science to support science content instruction. They conclude that such instruction has the potential to foster both NOS understanding as well as science content learning, although the results of the studies that they analyzed were somewhat inconsistent<sup>2</sup> and did not focus on the interplay of the two outcomes. Thus, there appears to be a strong argument for an inclusion of NOS in science instruction with regard to epistemic aspects of scientific concepts, whereas at the same time, there is only little empirical evidence that NOS instruction indeed supports the learning of science content—its epistemic and non-epistemic (i.e., disciplinary) aspects.

With the present article, we aim at contributing such evidence, reporting an empirical study that investigated how students' NOS understanding was related to their learning about a scientific concept, that of energy. This concept was selected because (a) it has been argued that that energy instruction should also take into account its epistemology (e.g., the universal nature of the concept, as well as its predictive power; Bächtold and Guedj 2014; Papadouris and Constantinou 2011) and (b) there already exists some first evidence that addressing NOS helps in understanding such epistemic aspects (Papadouris and Constantinou 2014).

## 2 Theoretical Background

NOS refers to the “epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge or the development of scientific knowledge” (Lederman 2004, p. 303). While there is an ongoing debate about what exactly constitutes NOS and how it can be distinguished from other concepts (see, e.g., Alters 1997; Smith et al. 1997), there is a strong consensus among researchers that science instruction—beside other

<sup>1</sup> The history of the role of NOS (or history and philosophy of science) in science teaching of course goes back much further than this. For a more detailed synthesis see e.g. Matthews (2015)

<sup>2</sup> In their research synthesis, Teixeira et al. (2012) found that five of the nine investigated studies reported positive effects of the didactic use of history and philosophy of science on content learning when compared to a control group, whereas two studies did not report such effect, and two further studies did not evaluate this. Furthermore, not all of the investigated studies consistently indicate the occurrence of a conceptual change. However, all of the five investigated studies that focused on the effect of the use of history and philosophy of science on students' NOS understanding found this effect to be positive.

NOS aspects—should convey ideas about the empirical and tentative nature of scientific knowledge, about the role of subjectivity and creativity in science, as well as about the status and function of scientific theories and laws (Kampourakis 2016; Lederman 2007; Lederman and Lederman 2014).

In general, NOS is viewed as an important topic to be taught in school science and, together with knowledge of scientific concepts, to contribute to scientific literacy (Lederman 2007; McComas and Olson 1998; NGSS Lead States 2013; OECD 2006; OECD 2013; Osborne et al. 2003). Besides viewing NOS understanding as important for its own value with respect to scientific literacy, scholars also expect NOS understanding to improve students' science content learning by fostering the ability to interrelate scientific content and, thus, to coherently develop scientific content knowledge (Driver et al. 1996). However, “the belief that an understanding of NOS will enhance students' subsequent learning of science subject matter [...] has yet to be systematically tested.” (Lederman 2007, p. 871). Whereas there already exist several studies investigating the influence of NOS (or, in a broader sense, beliefs about science) on learning in general, far less “empirical evidence has been provided that links nature of science knowledge with content knowledge” (Peters 2012, p. 881).

## 2.1 The Role of Beliefs About Nature of Science for Science Learning

The literature on beliefs about science not only provides insights in students' and teachers' understandings of NOS (e.g., Brickhouse 1990; Kang et al. 2005; see also Deng et al. 2011; Lederman 2007) and approaches to teach about NOS (e.g., Akerson et al. 2010; Khishfe and Abd-El-Khalick 2002; Lederman and Abd-El-Khalick 1998), but also thoughts about how students' NOS understanding may affect their learning in science. For example, Sadler et al. (2004) noted that students' conceptualizations of NOS would influence the manner in which they interpret and evaluate conflicting evidence, thus impacting their scientific reasoning skills. And with respect to conceptual change, Duit and Treagust (2003) argued that students' ability to engage in conceptual change may be closely linked to changes of views of the underlying concepts and principles of NOS.

The literature also provides several empirical studies that investigated the effect of beliefs about science<sup>3</sup> on students' learning skills and abilities. For example, Lin and Chiu (2004) reported that students with a more adequate understanding of NOS showed better and more conceptually based problem-solving strategies. Similarly, Tsai (1998) found that students with more sophisticated beliefs about science employed more meaningful strategies when learning science and showed higher metacognitive skills, whereas students with naïve beliefs about science tended to use more rote-like learning strategies. Finally, Cavallo et al. (2003) found that understanding the tentative nature of scientific knowledge would positively impact students' self-set learning goals; and Bell and Linn (2000) found a positive influence of

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<sup>3</sup> The science education, as well as the educational psychology literature, provide several concepts, which focus on epistemology in general and on epistemological aspects of scientific knowledge in particular (e.g. “epistemological beliefs”, “science-related epistemological beliefs”, “scientific epistemological beliefs”, “beliefs about science”, “ideas about science” etc.). These concepts show great overlap – all of them, for instance cover the aspects of certainty and justification of scientific knowledge. Examining, for example, the way in which understandings about NOS and science-related epistemological beliefs are conceptualized, they can be found not being identical, but very closely related (Neumann and Kremer 2013). As all of these concepts address students' beliefs about science, resp. Scientific knowledge, we decided to subsume them here under the general term “beliefs about science”.

sophisticated beliefs about science on students' reasoning and argumentation skills. Overall, we may note from these studies that the influence of beliefs about science on learning characteristics is well-investigated (Yang and Tsai 2012). However, these studies primarily focused on learning characteristics (learning strategies, scientific reasoning, ability to engage in conceptual change etc.) that are thought to *mediate* the relationship between beliefs about science on the one hand and science content learning on the other.

Far fewer studies have focused on students' NOS understanding and the learning of particular scientific content. Songer and Linn (1991), for example, found that students with dynamic views of science acquired a more integrated understanding of science content during instruction about thermodynamics than students with rather static views. Peters (2012) found that students working with NOS-oriented metacognitive prompts significantly outperformed a control group on assessments on both NOS understanding and content knowledge about electricity and magnetism. However, as the control group did not receive any metacognitive prompts at all, it cannot be unambiguously concluded that students' NOS understanding, and not the metacognitive prompts in general, accounts for this effect. In contrast to the above, Schwartz (2013) found that students' conceptions of NOS and conceptions of biology (genetics, molecular biology, and investigation of a human disease) are not necessarily interrelated.

Overall, the relation between beliefs about science and science learning seems to be well established theoretically but lacks sufficient empirical evidence. Many studies investigated the relation between NOS understanding and characteristics of science learning in general (e.g., Bell and Linn 2000; Cavallo et al. 2003; Lin and Chiu 2004; Tsai 1998), but not the learning of science content in particular. And studies focusing on the latter are not only rather scarce, but also convey inconsistent insights, some of them having found a relation between NOS understanding and science content learning (e.g., Peters 2012; Songer and Linn 1991), while others have not (e.g., Schwartz 2013). Thus, it can be concluded that, in fact, there is only very little empirical evidence on the validity of Driver and colleagues' (1996) science learning argument (Lederman 2007; Peters 2012). In particular, there seems to be a lack of research on the relationship between students' NOS understanding and their acquisition of an understanding of particular scientific concepts, for example through helping them to overcome their misconceptions regarding these concepts.

## 2.2 Understanding the Nature of Energy as a Theoretical Concept

One concept that is very important in science at all levels, but which students tend to have great difficulties with, is the concept of energy (Driver and Warrington 1985; Duit 2013; Neumann et al. 2013; Nordine et al. 2011). Students often conceptualize energy in quite different ways, some of which do not represent a scientifically accurate view. Many of these conceptualizations refer to the epistemology, i.e., “the nature of knowledge, its scope, foundations, and validity” (Schulz 2014, p. 1265), of the energy concept. Students may, for example, conceptualize energy as a quasi-material substance, or in a slightly more elaborated way as a substance-like quantity or a general kind of fuel (Duit 1987, 2013; Warren 2007). This view, however, does not resemble the way energy is taught in schools and universities, and eventually conveys an inadequate idea of what energy is (Bevilacqua 2014; Coelho 2014; Duit 2013; Warren 2007). Thus, it might be feasible to contrast the substance-like conceptualization of energy with a more elaborated one, taking into account the epistemological aspects of the concept. According to Feynman et al. (1963), energy can be conceptualized as a purely

theoretical, mathematical entity, which can be calculated for a number of different forms of energy, but which we do not really have knowledge about as to what it really *is*. At the same time, energy—as a scientific concept—has not just been discovered; the underlying theoretical construct has rather been developed in a successive process of assembling different pieces of knowledge to form a whole picture (Coopersmith 2015).

We define such epistemological aspects, as described in the above paragraph, as “nature of energy as a theoretical concept” (NETC). In accordance with Papadouris and Constantinou (2011), we view them complementary to the non-epistemological disciplinary aspects that mainly focus on the *properties* of energy as it is conceptualized and defined, like energy forms, transfer, conservation, and degradation (see, e.g., Duit 2013). NETC, in this sense, refers to understanding the *nature* of the concept as being a theoretical construct, as well as the *purpose* the concept of energy serves in being a universal framework that bears great predictive power (see Bächtold and Guedj 2014)—rather than to understanding and applying the disciplinary aspects of energy for problem solving. In order to value energy as a concept that is important both in science and in everyday life, students should understand that (1) energy is a universal concept in a sense that it can be applied to a broad variety of phenomena, and (2) energy is a theoretical concept that has been brought up by scientists, rather than having been developed, but which nevertheless holds great value due to its explanatory power (Papadouris and Constantinou 2011). To understand and appreciate these aspects, a sophisticated understanding of NOS seems important (Papadouris and Constantinou 2011). NOS, in this regard, could serve as a framework that students can refer to when engaging in learning about energy—and other scientific concepts—while at the same time reflecting on their ways of modeling these concepts and on how this is in accordance with a realistic view of science and scientific knowledge. Given proper instruction, students could be encouraged to use this epistemological understanding to also understand the different non-epistemological aspects of energy, with which they otherwise often experience difficulties.

There is one study that investigated how the teaching of NOS and science content aspects about energy would affect students’ conceptualization of energy as an invented, abstract theoretical framework (Papadouris and Constantinou 2014). In this study, activities concerning the invented and tentative nature of scientific knowledge, the difference between observation and inference, as well as the role of creativity in science were used to help students perceive energy as an “invented” construct. On the other hand, discussing the nature and value of unifying theories and criteria to judge the power and consistency of theoretical frameworks was thought to make students acknowledge that energy—despite being a human construct—serves as a powerful unifying concept that can help approaching a broad variety of phenomena. Papadouris and Constantinou (2014) descriptively showed that the integrated teaching of NOS and energy did not only provide students with a scientific context in which they could learn about certain NOS aspects, but that these NOS aspects themselves would influence the way in which students approach the concept of energy and how they would view scientific processes and theories as a whole. They did not, however, take into account the potential effect of NOS understanding on learning about the non-epistemological aspects of energy.

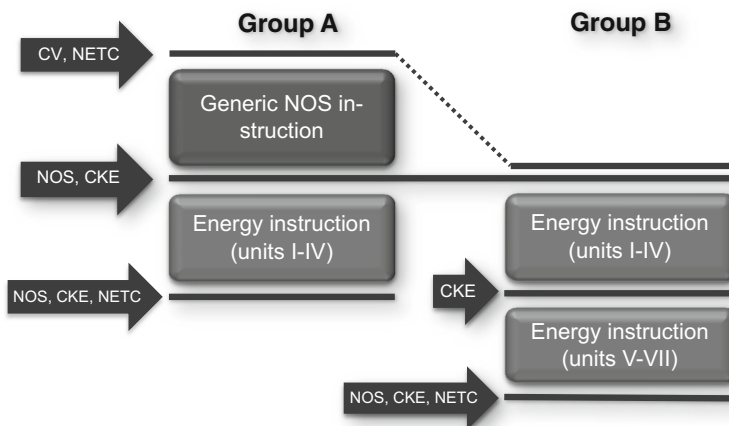
### 2.3 Aims of the Present Study

The present study aims to substantiate and extend what is already known about the interrelation between NOS understanding and science content learning. Given that the concept of energy is central to science, and that previous research provided first insights in

how NOS understanding may help students learn about epistemological aspects of this concept, we decided to focus on this as well. In particular, we build on the study by Papadouris and Constantinou (2014) and aim to substantiate their findings on the relationship between NOS understanding and students' acquisition of epistemological understanding about the concept of energy. Furthermore, we aim to provide additional evidence on whether NOS understanding also affects students' learning of non-epistemological aspects of energy (i.e., energy forms, transfer, conservation, and degradation). In order to reach this goal of research, the conducted study addresses the following research question: How is students' NOS understanding related to their learning about the nature of energy as a theoretical concept, as well as to their acquisition of physics content knowledge about energy?

### 3 Methods

To answer the research question, we performed a study in the context of a series of holiday science camps, each lasting 3 days in total. There were two distinct groups of students, group A and group B (see Fig. 1). All students received the same instructional units I–IV about energy. Group A students also received a unit of NOS instruction through generic activities in advance. In order to make up for the time group A students are exposed to the NOS instruction, we decided to implement additional energy units (V–VII) for the group B students after an interim assessment focusing on their energy content knowledge. Thus, a total of three different instructional units were used in the study: (1) A NOS unit, which was only administered to group A students; (2) a unit on energy, which was administered to all students; and (3) an additional unit on energy, which was only administered to the group B students. Each of these units lasted 270 min or three 90-min lessons each, similar to the typical timetables in school. However, breaks and unit lengths were organized in a way that they would fit instructional considerations, without strictly sticking to the 90-min schedule. All groups were taught by the same person, which is the first author of this article.



**Fig. 1** Study design: arrows show when tests are administered (CV = control variables, NETC = knowledge about nature of energy as a theoretical concept, NOS = knowledge about nature of science; CKE = content knowledge about energy)

### 3.1 Sample

The holiday science camp took place six times in total, three times for the group A schedule and three times for the group B schedule. The sample consisted of 6th and 7th grade students from different schools in the German state of Schleswig-Holstein. In total, 93 students applied for the science camp. Due to different reasons (e.g., becoming ill), not all of the applying students turned up at the science camp and some did not attend all 3 days. Altogether, we ended up with 82 students (26 female), who attended the whole science camp, and who took all tests as shown in Fig. 1. Forty-one students received instruction according to the group A schedule, and another 41 received instruction according to the group B schedule, being randomly assigned to either group A or B.

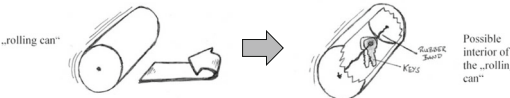
### 3.2 Instructional Materials

The energy units focused mainly on four aspects of energy that are commonly emphasized in the science education literature: (1) energy forms and sources, (2) energy transfer and transformation, (3) energy conservation, and (4) energy degradation (e.g., Duit 2013; Neumann et al. 2013). These aspects were taught in this sequence (1) to (4). However, taking into account that certain aspects may be interrelated, they were sometimes taught alongside each other. To motivate students, the whole science camp was about exploring a theme park. Rollercoasters, bungee jumps, and bumper cars were used to introduce and elaborate the forms of kinetic, potential, and elastic energy, as well as the transformation processes between these forms. Several of the activities and experiments have been taken and adapted from the IQWST curriculum (“Investigating and Questioning our World Through Science and Technology”), which is a well-established and tested curriculum, providing a hands-on approach toward energy and its conservation (Fortus et al. 2012). The energy units I–IV, which all students were taught, emphasized energy forms, transformations, and conservation, while degradation was only discussed at the end of the unit. The energy units V–VII, which only group B students were taught, included activities that repeated and consolidated the content taught before. Additionally, these units focused on deepening students’ understanding of energy conservation and degradation, e.g., by discussing different “perpetual motion machines” and examining why they could not run forever (see Fortus et al. 2012). Sample activities for the energy units are displayed in Table 1.

The NOS unit, which only group A students were taught, was based on generic NOS activities (Lederman and Abd-El-Khalick 1998), which were critically discussed in an explicit-reflective manner (see Akerson et al. 2000; Clough 2006; Khishfe and Abd-El-Khalick 2002). The administered NOS unit partly followed the schedule of the teaching approach of Papadouris and Constantinou (2011). Sample activities and NOS aspects that were addressed are given in Table 2. Within the NOS unit, no explicit connections to other science content—in particular, no connections to the concept of energy—were made.

Likewise, the units on energy did not include explicit teaching of NOS, nor was the energy content explicitly linked to the NOS aspects group A students were taught. Epistemological aspects of the concept of energy were discussed at several points in both groups, without linking it to NOS directly. The correspondent learning goal was for students to view energy as a theoretical framework that has been invented, elaborated, and refined in the history of science in order to explain a wide variety of phenomena (see Papadouris and Constantinou 2014). The teaching units for both groups A and B had the same learning goals about energy and

**Table 1** Sample activities for energy units

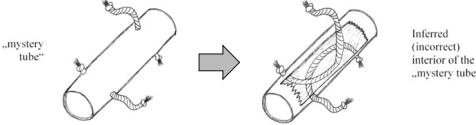
Activity	Energy aspect addressed	Activity description	Source
<p><b>Sample Activity: The Rolling Can</b> (Fortus et al. 2012)</p>  <p>When set rolling, the can will continue rolling in one direction until enough energy has been stored in the rubber band running inside of the can. Then it will stop and start rolling back in the opposite direction. Students are then asked to infer the possible interior of the rolling can from what they observe and from what they know about energy transformation and conservation.</p>			
The Rolling Can	Energy forms, transformation, conservation, and degradation	See above	Fortus et al. (2012)
"Dennis the Menace"	Nature of energy as an invented construct Explanatory power of the energy concept	Students read and discuss a text by Richard Feynman on the nature of energy as a mathematical construct, which cannot be measured directly, but which holds great explanatory power. The question whether and why it is still legitimate and useful to use the same term "energy" for the different forms is discussed with the whole group.	Feynman et al. 1963
Rollercoaster and Bumper Car	Energy forms and transformation	To introduce and elaborate kinetic and gravitational potential energy, students investigate the relation between the height of a marble on a rollercoaster and its final speed when rolling down. Likewise, they examine the relation between the speed of a can and its impact on a ball of modeling clay.	Fortus et al. (2012)
Perpetual Motion Machines	Energy degradation	Students are shown different (electrically-driven) "perpetual motion machines". They are then asked to come up with a statement, whether the machine will go on forever and an explanation, why they think so. In a following discussion, the law of energy conservation and its implications on physical systems are discussed.	Fortus et al. (2012)

employed similar teaching methods (see Table 3). Both units had been tested in a pilot study with five and six students, respectively, in advance to the holiday science camps. We used the pilot study to gain experience about the time students take to work on the respective tasks and experiments, as well as about how students would react in class discussions. After this pilot study, both units were slightly adapted according to the teaching experiences.

**3.3 Assessment Instruments**

Before and after the instructional units, we assessed students' (1) NOS understanding, (2) understanding of the nature of energy as a theoretical concept, (3) energy content knowledge,

**Table 2** Sample activities for NOS units

Activity	NOS aspect addressed	Activity description	Source
<p><b>Sample Activity: The Mystery Tube</b> (Lederman &amp; Abd-El-Khalick 1998)</p>  <p>Inferred (incorrect) interior of the "mystery tube"</p>			
The Mystery Tube	Difference between observation and inference Role of creativity in science Tentativeness of scientific knowledge	Students are given a tube with four strings going out of the tube. Pulling one string makes one or more of the others move inside the tube in a seemingly random pattern. Students are then asked to describe their observations. Finally, students are asked to come up with theories as of how the tube might look like on the inside. In a subsequent discussion, the different ideas are discussed, including the question which theory would be the "best". In this regard, important NOS aspects, such as the difference between observation and inference, the role of creativity in science, and the tentativeness of scientific knowledge can be explicitly discussed.	Lederman & Abd-El-Khalick (1998)
Tricky Tracks	Difference between observation and inference Role of creativity in science Tentativeness of scientific knowledge	Students are given a picture with two lines of footstep-like dots. They are asked to formulate their observations and to come up with theories as to what might have happened. Students learn that scientific theories cannot be classified as "right" or "wrong", but are rather judged by criteria like simplicity and explanatory power.	Lederman & Abd-El-Khalick (1998)
The Aging President	Subjectivity in science	Students are presented a sequence of pictures within which a drawing of a mid-aged man's face successively turns into a drawing of a young woman. The influence of students' previous knowledge on their perception of the pictures and the notion of <i>objectivity</i> in science are discussed.	Lederman & Abd-El-Khalick (1998)
Mystery Bones	Subjectivity in science	Students are given a variety of skeleton parts from an unknown animal and are asked to put them together. The influence of their previous knowledge on their result is discussed.	Project ICAN (Lederman et al. 2012)
Historical narrative: Aristotle	Role and nature of scientific theories Tentativeness of scientific knowledge	Students read a narrative about Aristotle's theory of motion. The following discussion focuses on the general tentativeness of scientific theories, but also conveys that Aristotle's theory – although it is outdated by now – still had great value for a long time due to its explanatory power.	Papadouris & Constantinou (2014)



**Table 3** Pedagogical framework of the study

	Group A	Group B
Approach	Energy units I-IV: Traditional approach; content topics follow recommendations from science education research (energy forms, transformations, conservation) NOS unit (prior to energy unit): explicit-reflective approach; generic NOS activities followed by epistemic discourse (difference between observation and inference, nature of scientific theories, subjectivity)	Energy units V-VII: Traditional approach; additional supplementary activities; special focus on energy conservation and degradation
Context	Activities embedded in theme park setting	
Teaching methods	Direct instruction, discussion of content-related concepts, worksheets, pre-designed group experiments and activities	
Intended outcomes	Energy units I-IV: Mastery of energy forms, transformations and conservation	Energy units I-IV: Mastery of energy forms, transformations and conservation Energy units V-VII: Mastery of energy forms, transformations, conservation and degradation
Sample	3 camp groups with a total of 41 students	3 camp groups with a total of 41 students

and (4) different control variables. The respective assessment instruments are described in more detail in the following paragraphs.

### 3.3.1 NOS Understanding

Students' NOS understanding was assessed by using multiple choice items from the Nature of Science and Scientific Inquiry questionnaire (NOSSI, Neumann 2011). NOSSI items were designed to assess students' understanding about nature of scientific knowledge and about nature of scientific inquiry in the context of the history of physics (see sample item in Table 4). Items included a short text on a historical event (e.g., the development of models of the solar system) and then asked the students to identify and reflect on NOS aspects related to this event. Thirty NOSSI items were selected according to the NOS aspects emphasized in the NOS unit. In order to estimate item statistics, the items were administered to 172 8th and 9th graders in advance of this study. Based on the findings from this pilot study, a set of 22 items was chosen according to item statistics and reliability while maintaining representation of the selected NOS aspects. The NOS test was administered to the students before the beginning of the first energy unit; that is, group A students were administered the NOS test after having received generic NOS instruction, and group B students at the beginning of their science camp. Originally, the NOSSI questionnaire had been used as a dichotomously scored test, evaluating each given answer as being right or wrong (Neumann 2011). Other instruments, such as the VNOS (Lederman et al. 2002), typically include a third category ranking students' views as either naïve, informed, or mixed. Therefore, in the present study, to incorporate this ranking and to not lose information embedded in the distractors, the NOSSI items were scored using partial credits. To this end, each correct response option was scored as 2 credits, and each distractor was scored as representing either a mixed (1 credit) or a naïve (0 credit) understanding of NOS. To ensure scoring of the distractors (i.e., 1 or 0 credits), two authors of this article rated the distractors independently. On 46 of the 66 distractors, there was agreement among the two raters; the scoring for the remaining 20 distractors was discussed until agreement was reached.

**Table 4** Sample items for used assessment instruments

Variable	Sample item	Source
NOS	<p>Item stem: People have wondered about our solar system and what it looks like for a long time. In doing so, each model was dependent on their world view. In ancient times, Aristotle had the idea that the planets orbit the earth on different spheres. Later on, orbits were observed which could not be explained with this model. Thus, Ptolemy developed a new model. However, as time went on, some new observations were made and they could not be explained even using Ptolemy's model. Based on this new information, scientists added more details to Ptolemy's model. Thus, it became very complex and confusing. In late medieval times, Nicolaus Copernicus thought that there had to be a less complex model to describe the world. Thus, he worked out another model with the sun in the center instead of the earth. However, his model did not lead to more precise calculations than the old one. In some points, Johannes Kepler changed Copernicus' model and formulated three laws. He checked these laws with new, more precise observations. Using this advanced model, the orbits of the planets could be predicted very precisely.</p> <p>Item: Aristotle already had modeled the solar system. Why did Ptolemy develop another model? Complete the sentence. Aristotle's model...</p> <p>a) ... neglected laws that had been proved right before. b) ... was wrong because it had not become a law. c) ... had been regarded to be true for such a long time that it had to be improved. d) ... could only explain very few observations. (correct)</p>	Neumann (2011)
NETC	The formulae for the different forms of energy (e.g. kinetic energy or gravitational potential energy) do differ. Why do scientists nevertheless use the word "energy" for these different phenomena?	Self-developed
NETC	Are there similarities among the different energy forms from a scientific perspective?	Self-developed
CKE (energy forms)	<p>An object is lying on a table. Which factors influence its gravitational potential energy (GPE)?</p> <p>a) The object's GPE depends on its speed and on its mass. b) The object's GPE depends on its mass and on the height of the table. (correct) c) The object only has GPE when it's moving. d) The object only has GPE when it is not moving.</p>	Adapted from Nordine (2007)
CKE (energy degradation)	<p>During the transfer of electric energy across a high voltage power line, less electric energy is available at the final destination than at the starting point of the transfer. What happened to the missing energy?</p> <p>a) The missing energy has been used up. b) About half of the missing energy has been transformed into thermal energy, the rest has been used up. c) The missing energy has completely been transformed into thermal energy. (correct) d) The missing energy is transferred back to the power plant and is completely transformed into thermal energy there.</p>	Adapted from Swackhamer et al. (2005)

### 3.3.2 Understanding of the Nature of Energy as a Theoretical Concept

In order to assess students' understanding of the nature of energy as a theoretical concept (NETC), a set of open-ended items was designed. In addition to the four "traditional" aspects of energy which are mentioned in the literature (Duit 2013; Neumann et al. 2013), the concept of energy also has some facets that are more epistemological in nature (Papadouris and Constantinou 2011). First, energy can be regarded as a very universal theoretical concept, bridging several scientific domains and being applicable to a broad range of scientific phenomena. Second, energy can be regarded as something that has

been invented by scientists in order to explain phenomena and make predictions, rather than something that has been discovered (Papadouris and Constantinou 2011). Accordingly, NETC items focused on energy as an overarching construct and as a theoretical framework that has been “invented” by scientists, but nevertheless holds great explanatory value (see sample items in Table 4). We employed items from already established instruments (Nordine 2007; Papadouris and Constantinou 2014) and complemented the item pool by self-developed items. The item pool (9 items) was administered to 89 eighth and ninth graders from three different schools in northern Germany in advance to the study. After this pilot study, the items were revised, removed, or rearranged according to item statistics, reliability, and student answers. This process resulted in a set of 10 multiple-choice and open-ended items, which were used in the present study. Students’ NETC understanding was assessed before and after the whole teaching unit (see Fig. 1). For data analysis, NETC items were scored using partial credits based on a scoring manual.

### 3.3.3 Content Knowledge About Energy

Assessment on students’ understanding of energy consisted of multiple choice and open-ended items, focusing on declarative and conceptual knowledge about energy. Each CKE item was assigned to one aspect of energy: (1) energy forms and sources, (2) energy transformation, (3) energy conservation, and (4) energy degradation. Sample items are given in Table 4. Whenever possible, we used items from already established instruments on energy (Bader 2001; Nordine 2007; Swackhamer et al. 2005). In order to create an even distribution between the respective energy aspects, additional items were designed. To this end, we generated an item pool of 60 items. In a pilot study, these items were administered to a sample of 172 students of eighth and ninth grade from three different schools in northern Germany to estimate item statistics.

For the present study, 30 items were selected according to item statistics and reliability, while an even distribution of items across energy aspects and contexts was maintained. For the item selection, we also took into account that the piloting was with 8th and 9th graders whereas the science camp participants were 6th and 7th graders; therefore, we selected easier items. An overview of the CKE items is given in the online supplementary material. In the science camp study, content knowledge about energy was assessed before and after the first energy units I–IV. Group B students were administered the CKE test for a third time after the second units on energy V–VII as well (see Fig. 1). For data analysis, multiple-choice items were scored dichotomously, with only one correct answer per item; open-ended items were scored using partial credits based on a scoring manual.

### 3.3.4 Control Variables

In order to examine whether the groups are comparable, a set of control variables was assessed. Control variables included interest in physics, motivation, and cognitive abilities. We employed well-established instruments on students’ interest in physics (Köller et al. 2000) and students’ motivation (Fechner 2009). To assess students’ cognitive abilities, we employed a subscale of a well-established intelligence battery (Heller and Perleth 2000). The used subscale focused on students’ non-verbal cognitive abilities by asking students to complement figural analogies. All control variables were assessed at the very beginning of the science camp (Fig. 1).

### 3.4 Data Analysis

Items were coded as described above. Missing responses in open items were scored as no credit, and sum scores were calculated for each test instrument. In fact, we observed a relatively high number of missing responses on open-ended items in particular (NETC and CKE). Certainly, this is a problem of open items against multiple-choice items; students are typically more likely to provide an answer on multiple-choice items, even if they do not know or are unsure about the answer, whereas they may rather leave a blank page on open items. Open-ended items, however, provide more in-depth insights of students' thinking. We moreover observed that (1) missing rates were highest on the NETC pre-test and that (2) for all instruments, the missing rates decreased from pretest to posttest I and again to posttest II. Given that at the time of the pretest, the students had had no or only little exposure to the assessed content, and given that in the posttests, instruction within the intervention obviously led to smaller missing rates, we may interpret a missing response as an indicator that students would skip a question if they did not feel able to answer it. This procedure, in turn, means that the CKE and NETC pretests were too difficult for the sample. We nevertheless decided to keep them the same as in the posttests in order to calculate learning gains from pre- to post-measures.

The focus of our data analysis was on investigating students' learning gains on both NETC and CKE in relation to their NOS understanding. To this end, we used a multilevel linear model approach (e.g., Field et al. 2012), in which several models were calculated that estimate linear regressions of the NETC (or CKE) outcome at the different measurement points while considering dependency in the data. First, main effects of the predictor variables were included (measurement point, NOS pretest score, cognitive abilities), and then, interaction effects were added. As there are multiple measures for NETC and CKE for each student (pretests and posttests), the measurement point was included as a within-factor in the linear models, while the other variables were included as between-factors. The resulting regression models were then compared using an ANOVA, testing each successive model on whether it significantly increased the amount of variance explained by adding the respective predictor variable. A significant *main* effect, e.g., of the measurement point would imply that the NETC (or CKE) score significantly depends on the time of the measurement, meaning that there is a statistically significant learning gain. A significant *interaction* effect, e.g., for the interaction between NOS pre-test score and measurement point, would imply that the observed learning gain significantly differs in relation to students' NOS understanding. Instead of using this approach and including both measures (pre and post) as separate data sets, we could have determined the individual students' learning gains as the difference between their post- and pre-measures (e.g., NETC-post minus NETC-pre), and subsequently could have correlated these differences with students' NOS understanding. In such approach however, we would have used aggregated data and would have lost variance, and thus information, actually provided by the data (Field et al. 2012).

## 4 Results

### 4.1 Group Differences

Prior to our focus analyses, we examined the reliability of the instruments. Reliability measures were found acceptable for all used instruments (Cronbach's alpha between .64 and .89), indicating that the underlying constructs were robust and consistent and that the data

at hand may be used for further analyses. Table 5 shows the means for group A and group B prior to the teaching unit on energy (for details on reliability and descriptive statistics for the whole sample, see Tables 6 and 7 in the appendix). To determine whether the two groups differ, we used independent  $t$  tests (e.g., Field et al. 2012). Regarding all variables, groups were found to not differ significantly ( $p > .05$ ) prior to the energy treatment. Note that this means that we also did not find a significant difference between the two groups regarding NOS understanding—even though group A, but not group B, had received NOS instruction prior to the assessment (see Figs. 1 and 2). However, in the whole sample, we found quite large variance regarding students' NOS understanding ( $M = 28,30$ ;  $SD = 7,24$ ;  $\min = 11$ ;  $\max = 42$  of possible 44 credits). We therefore employed regression-based analyses to investigate how NOS understanding is related to the learning about energy.

## 4.2 Analyses

We performed a stepwise analysis of our data. First, we investigated students' learning gain in understanding the nature of energy as a theoretical concept (NETC). Second, we investigated how students' NETC understanding related to their NOS understanding. Third, we examined students' learning gain on content knowledge about energy (CKE), and fourth, how this CKE learning related to their NOS understanding. It is important to note that only the investigations of the CKE learning gain between pretest and posttest I were conducted for the whole sample collectively.<sup>4</sup>

### 4.2.1 Nature of Energy as a Theoretical Concept

To investigate students' learning gain regarding NETC, a multilevel linear model approach was used, comparing a baseline model with a model that uses the measurement point as predictor for students' NETC score. We found the inclusion of the measurement point to significantly increase the amount of variance explained by the model for both groups ( $p < .001$ , see Fig. 3), indicating a significant gain in students' NETC understanding. The inclusion of an interaction between students' belonging to either group A or B and their NETC learning gain did not significantly improve the model ( $\chi^2(1) = 0.09$ ,  $p = .763$ ), indicating that both groups had a similar learning gain regarding NETC after their respective teaching unit.

### 4.2.2 Nature of Science and Nature of Energy as a Theoretical Concept

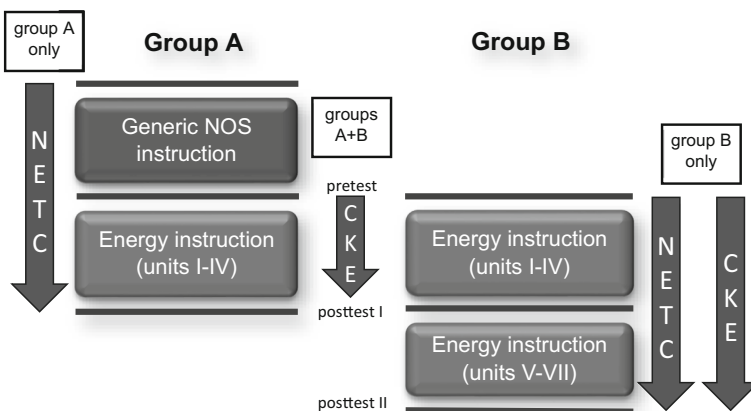
As a next step, we investigated the interaction between students' prior NOS understanding and their learning gain regarding NETC. To this end, a multilevel linear model approach was used, subsequently including (1) measurement point, (2) students' NOS understanding prior to the teaching unit, (3) students' cognitive abilities, (4) the interaction between students' NOS understanding and measurement point, and (5) the interaction between cognitive abilities

<sup>4</sup> The investigations of the CKE learning gain from pretest to posttest II were conducted only for group B. The reason for this lies in the fact that for the whole sample (group A and B students together) we had only data to determine the learning gain along the energy units I-IV (from pretest to posttest I), whereas for the sub-sample of group B students, we also had data to determine the learning gain along the energy units V-VII (that is from pretest over posttest I to posttest II, see Figure 2). The investigations of the NETC learning gain were conducted for group A and B students separately, as the kind of instruction (i.e. A: NOS + energy units I-IV vs. B: energy units I-IV + V-VII) differed between the NETC pre and post measurement (see Figure 2).

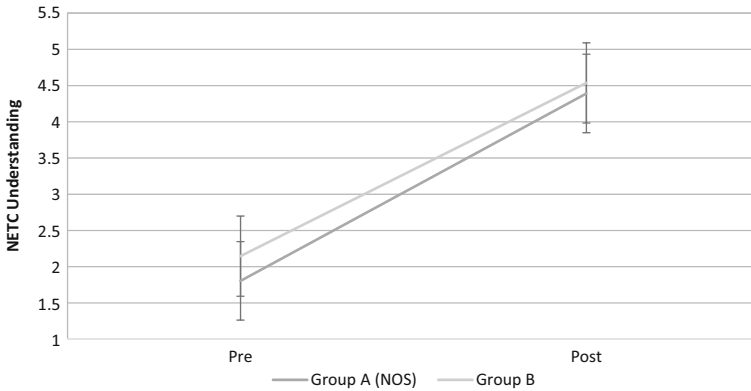
**Table 5** Group differences for variables before the first teaching unit about energy

Variable	Mean group A	Mean group B	<i>p</i> value	Test method
Motivation	3.99	4.15	.20	Independent t-test
Interest	3.37	3.53	.39	Independent t-test
Cognitive abilities	51.03	49.59	.52	Independent t-test
NOS	28.75	27.85	.58	Independent t-test
Energy	11.91	11.33	.59	Independent t-test
NETC	1.80	2.14	.43	Independent t-test

and measurement point as predictors for students' NETC score (see Sect. 4). These analyses were performed separately for groups A and B. For group A, the subsequent inclusion of both measurement point and NOS understanding significantly improved the amount of variance explained by the model (main effects). The significant main effect of the measurement point means, just as in the first analysis above, that students' performance on the NETC questionnaire significantly differs between pretest and posttest. Figure 4 shows that students performed significantly better in the posttest. The main effect of NOS understanding means that students with a higher NOS score also performed better on the NETC questionnaire in both pretest and posttest. This is depicted in the incline of both regression graphs (pretest and posttest) in Fig. 4. The inclusion of cognitive abilities did not further improve the model ( $p = .69$ ). The interaction between NOS understanding and measurement point, however, did ( $\chi^2(1) = 5.33, p < .05$ ). This interaction effect means that students' change in their NETC score from pretest to posttest significantly differs in relation to their NOS understanding. Figure 4 shows that the average learning gain—as represented by the distance between the linear regression graphs—appears to be higher for students with a high NOS score in the pretest. Students with a low NOS score appear to have a much lower learning gain. The interaction between cognitive abilities and measurement point did again not significantly improve the model ( $p = .68$ ). For the group B subsample, results were similar (significant main effects for measurement point



**Fig. 2** Performed analyses. NETC learning gains (indicated by the arrows) were analyzed for both groups separately, as their instruction between NETC pretest and posttest differed. As both groups received the same unit on energy, CKE learning gain from pretest to posttest I was analyzed for both groups collectively, while CKE learning gain from pretest to posttest II was analyzed for group B only

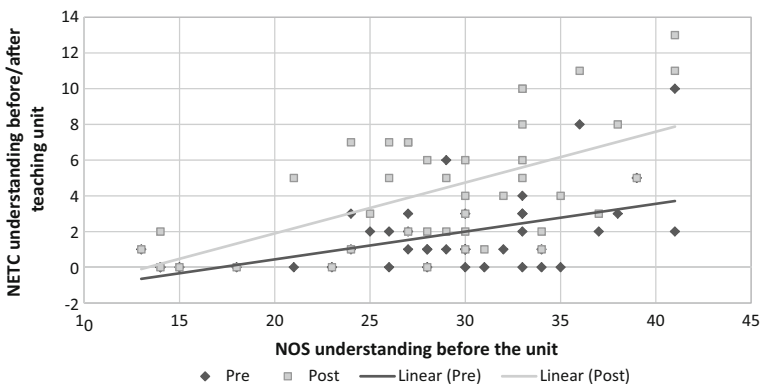


**Fig. 3** Students’ understanding of the nature of energy as a theoretical concept (NETC) before and after the teaching unit

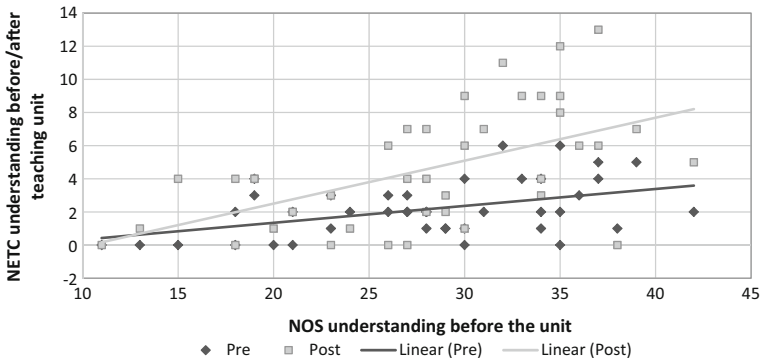
and NOS understanding, significant interaction between NOS understanding and measurement point ( $\chi^2(1) = 6.93, p < .01$ , see Fig. 5). However, for this subsample, we found a significant main effect for cognitive abilities, as well as a significant interaction between cognitive abilities and measurement point ( $\chi^2(1) = 7.03, p < .01$ ), meaning that cognitive abilities also relate to the NETC learning gain. Investigating scatter plots, we found that in group A, measures for cognitive abilities and NETC were more heterogeneous than those in group B, with several measures lying quite far away from the regression graph. Thus, the impact of cognitive abilities remains somewhat unclear. Perhaps, a larger sample size would lead to more consistent data, thus clarifying the role of cognitive abilities for students’ NETC learning gain.

4.2.3 Content Knowledge About Energy

In addition to students’ learning gain about nature of energy as a theoretical concept, we also examined students’ learning about energy content knowledge (CKE). Again, we employed a multilevel linear model approach. Taking into account the CKE results from all of 82 students before and after the first units about energy (units I–IV), we found a highly significant learning gain, represented by a significant improvement of the amount of variance explained through



**Fig. 4** Group A students’ understanding of the nature of energy as a theoretical concept (NETC) before and after the teaching unit in relation to their NOS understanding before the unit

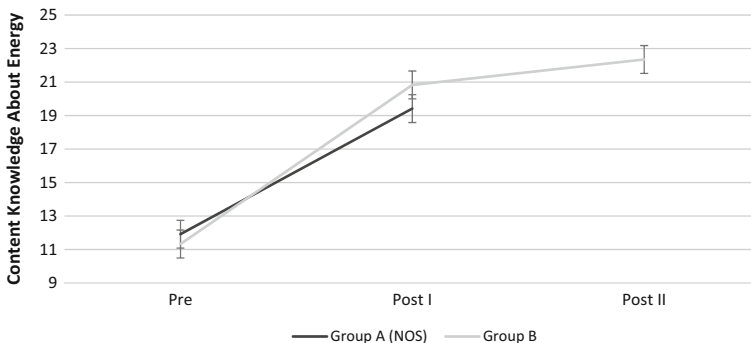


**Fig. 5** Group B students’ understanding of the nature of energy as a theoretical concept before and after the teaching unit in relation to their NOS understanding before the unit

inclusion of the measurement point as predictor in the model ( $\chi^2(1) = 270.48, p < .001$ ). That is, students improved their CKE during the first units on energy. Additionally, we also investigated group B students only (those who received instruction on energy units I–IV and on units V–VII). Within this sub-sample, we performed the same analyses, but took into account three points of measurement, pre unit I, post unit IV, and post unit VII. Across these three points of measurement, we again found a highly significant learning gain ( $\chi^2(2) = 269.17, p < .001$ ). However, this corresponds to a high learning gain along units I through IV, and only a small, non-significant ( $p = .091$ , see Fig. 6) learning gain along units V through VII.

4.2.4 Nature of Science and Content Knowledge About Energy

Finally, we investigated the relationship between students’ NOS understanding and their CKE learning gain. Again, we performed multilevel regression analyses, subsequently including (1) measurement point, (2) students’ NOS understanding prior to the teaching unit, (3) students’ cognitive abilities, (4) the interaction between students’ NOS understanding and measurement point, and (5) the interaction between cognitive abilities and measurement point as predictors for students’ CKE score. For group A and group B students collectively, we found significant improvements of the model for the inclusion of students’ NOS understanding ( $\chi^2(1) = 22.52, p < .001$ ) (model 2), and their cognitive abilities ( $\chi^2(1) = 16.70, p < .001$ ) as predictors (main



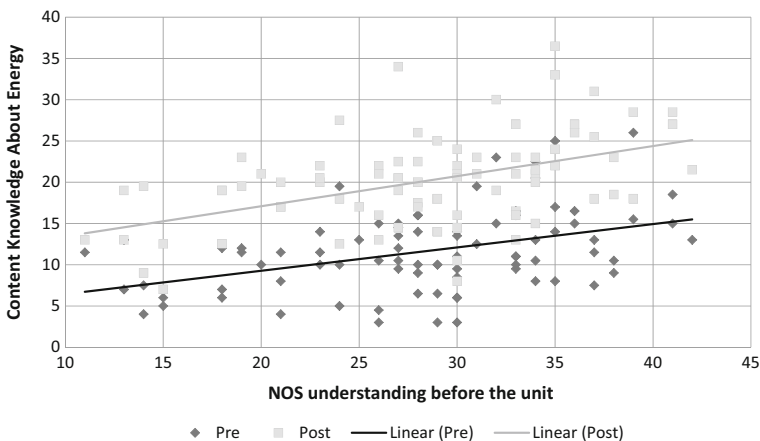
**Fig. 6** Group A and group B students’ content knowledge about energy at the different measurement points



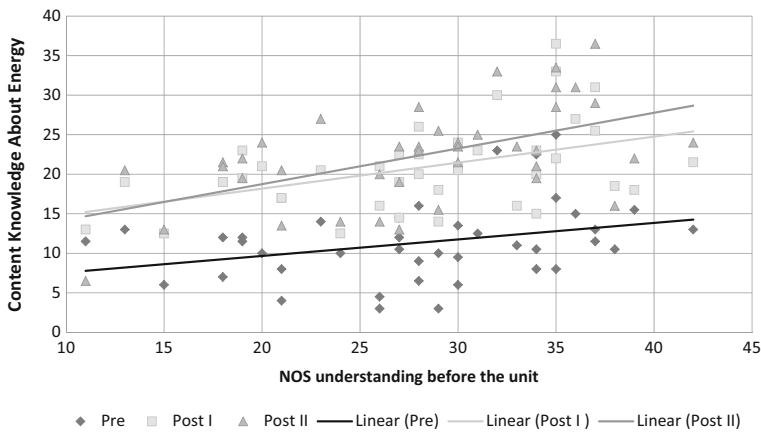
effects). Figure 7 shows students' CKE results in relation to their NOS score, taking into account the measurement at points one (pretest) and two (posttest I, after energy unit IV). It shows that, on average, students with a higher NOS score achieved higher CKE test scores at both measurement points.

However, students' average learning gain, which is represented by the distance between the two linear graphs in Fig. 7, does not seem to be strongly related to their NOS understanding, as both lines are nearly parallel. This conclusion is supported by the fact that the interaction effect between NOS understanding and CKE measurement point is not significant ( $\chi^2(1) = 1.27$ ,  $p = .260$ ). There is, however, a significant interaction between students' cognitive abilities and measurement point ( $\chi^2(1) = 9.20$ ,  $p < .01$ ), implying that students' learning gain regarding CKE significantly differs in relation to their cognitive abilities. Investigating the respective regression graphs, it appears that students with higher cognitive ability scores have on average a higher learning gain regarding CKE than students with lower cognitive ability scores.

For group B students, we performed analyses for the same predictors (1) to (5), this time including all three measurement points for CKE (pre unit I, post unit IV (posttest I), and post unit VII (posttest II)). In this sub-sample, including NOS understanding and cognitive abilities did again both significantly improve the amount of variance explained by the respective model ( $p < .001$ ), thus representing significant main effects. Additionally, we found the interaction between NOS understanding and CKE measurement point significant ( $\chi^2(1) = 6.32$ ,  $p < .05$ ). Most interestingly, we found the learning gain from posttest I (after unit IV) to posttest II (after unit VII) to differ in relation to students' prior NOS understanding (see Fig. 8, in which the respective graphs intersect). Including the interaction between cognitive abilities and measurement point did not significantly improve the model ( $\chi^2(1) = 5.44$ ,  $p = .066$ ). Overall, the analysis for group B implies that students with higher NOS understanding seemed to have learned more about energy (i.e., they have a higher learning gain on CKE) as compared to students with a low NOS understanding. As this finding refers to the learning gain along units V–VII, which mainly focused on energy degradation, this may indicate that NOS understanding might in fact be helpful for students' learning about energy degradation (but only tend-wise, as the learning gain for units V–VII was only small and not found to be significant).



**Fig. 7** Students' content knowledge about energy before and after energy units 1–4 in relation to their NOS understanding



**Fig. 8** Group B students' content knowledge about energy before and after energy units 1–4 (pre/post I) and after energy units 5–7 (post II) in relation to their NOS understanding

However, as we only conducted correlational analyses, valid causal claims cannot be established.

## 5 Discussion

In the present study, we investigated to what extent students' learning about the concept of energy would relate to their NOS understanding. In a holiday science camp, two groups of students ( $n = 82$ ) received instruction on energy, with one group also receiving instruction on NOS beforehand, and the other group receiving additional energy instruction after an interim assessment. The NOS instruction did not, however, result in students having higher scores on the NOS instrument; we therefore decided to not conduct analyses as one typically would in a treatment group/control group design. Hence, we used regression-based analyses in order to find out how students' learning about the nature of energy as a theoretical concept (NETC), as well as about non-epistemological aspects of energy, would relate to their NOS understanding. First, we investigated how students' understanding of the NETC relates to an adequate NOS understanding. Since we took measures of students' NETC understanding prior to the first unit and after the last unit of instruction, and since group A and group B students received different instruction in between, we analyzed the relationship between NOS and NETC understandings for the two groups separately. For both groups, we found students' learning about the nature of energy as a theoretical concept to be significantly related to their NOS understanding. Students with naïve views about NOS seem to progress in their understanding of NETC much slower, as compared to students with more informed views of NOS. This implies that students might perceive the energy concept differently when they have an adequate understanding of NOS, compared to when having a naïve understanding of NOS. Our results substantiate the findings of Papadouris and Constantinou (2014), providing evidence that NOS understanding might have an impact on the way students understand the concept of energy. Students with more adequate NOS understanding seemed to be far more able to grasp the epistemological aspects of the concept, leading to a more sophisticated understanding of energy as a theoretical concept.

Going beyond the study of Papadouris and Constantinou (2014), we also investigated whether students' NOS understanding would relate to their learning of "traditional" science content aspects of energy (CKE). For the first part of energy instruction (i.e., units I to IV), we found no relation between students' NOS understanding and gain in energy understanding. For those students who had received the first and the second part of energy instruction (i.e., units I–IV and units V–VII), however, we found a significant correlation between NOS understanding and gain in energy understanding throughout the second part of instruction. That is, students with a more adequate NOS understanding gained more knowledge about energy as taught in the units V to VII. When we took a closer look to the energy items, we found that this gain nearly fully stems from a gain in understanding energy degradation. Remember that units I to IV covered the teaching of the forms, transformation, transfer, and conservation aspects of energy, whereas units V to VII also included teaching of energy degradation. Although the gain in CKE understanding V to VII itself was not significant during these units, these results still provide first evidence that an adequate NOS understanding might in fact be related to the learning of the energy concept.

However, this may be not indispensable for mastering the more basic aspects of energy, which are used to describe idealized physical systems (forms, transformation, transfer, and conservation), but it may help students understand energy degradation, a concept that has been found to be quite difficult for them (Neumann et al. 2013). In physics instruction, energy is often introduced using idealized systems, where energy degradation does not occur. Additionally, in many phenomena, the degradation of energy (e.g., through friction) is neither visible nor easily detectable, making it difficult to grasp. Understanding the nature of energy as a theoretical concept (to which NOS understanding appears to be related, according to our analyses) could help students to understand energy degradation. If they are aware that energy is a rather theoretical entity, this could help them distinguish idealized systems from "real-world" ones. Understanding energy as a numerical, quantifiable concept could make it easier to understand that, through calculating energy differences between initial and final states of a system, energy degradation can be mathematically tracked, even if it cannot easily be sensed or measured.

For all analyses, we also examined the role of students' cognitive abilities, as they might potentially confound with both NOS understanding and learning gains, and thus blur the validity of the results reported above. We found the correlation between NOS understanding and students' cognitive abilities to be positive, but relatively small (Pearson's  $r = .275$ ,  $p = .013$ ), showing that the two factors are mostly independent from each other (only about 8 % of the variance of the NOS score can be explained by the variance of the cognitive ability score). Furthermore, the relation of NOS understanding (or cognitive abilities, respectively) to the examined outcome variable differed for the different outcome variables. This finding also indicates that the two factors are independent. For items concerning energy degradation, for example, we found NOS understanding to be a better predictor for students' learning gain than cognitive abilities, while for items concerning energy conservation, students' learning gain appeared to stronger relate to cognitive abilities, as compared to NOS understanding.

In summary, our study provides evidence that NOS understanding in fact is related to the learning of science content. An adequate NOS understanding seems to be of particular importance for concepts that are somewhere between pure disciplinary content knowledge and more general knowledge about NOS (understanding the nature of energy

as a theoretical concept), as well as for more advanced science concepts (e.g., energy degradation). The results of this study can, however, not simply be generalized for scientific concepts other than energy, as our instruction and assessment focused specifically on this concept. Nonetheless, the results of this study provide some implications as to how future research might further address the science learning argument, i.e., if and how NOS understanding impacts the acquisition of science content knowledge.

## 6 Limitations

Although our study provides insights in the relationship between NOS understanding and science content learning, it also has some limitations. The first, and probably most evident limitation is that the employed NOS teaching unit did not result in group A students having higher NOS measures than group B students prior to the energy instruction. We see several potential reasons for this. First, the NOS instruction may have been too short (270 min in total). Second, the NOS aspects were not taught integrated in scientific content, but rather in a generic manner, which may make them more difficult for students to grasp. Third, students from grades 6 and 7 may have been too young to fully understand the addressed NOS aspects. And finally, our NOS instrument may have been not sensitive enough to map students' progress as NOS was covered more broadly than taught in the NOS units. Thus, with the expected effect of the NOS treatment not found, we were not able to perform analyses that could substantiate a causal relationship between NOS and science content learning. We were, however, able to perform regression-based analyses to investigate the relationship between NOS understanding and learning about energy.

Our study moreover faces a limitation due to the setting of a science camp. Since we solicited participants in our study voluntarily, and given the fact that the study took place during students' holidays, we may have investigated a biased sample of students. That is, participants may have been more interested and motivated in learning science than average. In fact, we cannot rule out such positive selection with respect to motivation as the mean motivation was found rather high (Table 7 in the appendix). This may indicate a selection bias but could also reflect a social desirability bias. In contrast, students' interest was found to be about average on the employed scale (Table 7). We assume that some participants actually wanted to participate because they were interested in science, whereas others were rather sent by their parents (for example to be under supervision during holidays and working hours), which may be reflected in the only average interest. Nevertheless, our study may only carefully be transferred from our chosen setting of a lab-study into a field study setting (e.g., the intervention included in the regular teaching at schools). The students' population in the field may in fact significantly differ from the sample investigated here. Also, organizational differences between a classroom setting and a science camp setting (e.g., single 45–90 min lessons spread over weeks compared to a continuous course as in the science camp) may impact the findings as well.

Finally, another source of limitations stems from our treatment of missing responses on open-ended items, which we scored as no credit. We observed a relatively high number of missing responses on open-ended items in the NETC and CKE instruments, with missing rates in the posttest(s) being lower than in the pretest. As students were given enough time to answer the questionnaires, we interpreted this as an indicator that students would skip a question if they did not feel able to answer. As most of the students had not had any formal physics

instruction before the unit (in particular neither in the field of energy, nor NETC), these topics might have appeared completely new to them and instead of potentially expressing a wrong answer, students might have just left the respective boxes blank. Thus, we treated missing answers as no credit when calculating the sum scores for the respective instruments. However, another interpretation might of course be that some students did not write down an answer due to fatigue or a lack of motivation.

In addition to the results reported here, we examined this effect by calculating ratio scores instead of sum scores for all students as well, i.e., the sum score of each student was divided by the maximum score he/she could have achieved on the items that he/she actually gave an answer to. Thus, for students who only answered few questions but scored some credits on these, the ratio score would be higher in relation to students with the same total score, but with more questions answered. When recalculating the analyses based on these ratio scores, the same tendencies as reported here were found as well, but not all effects became significant. For instance, we found a significant relation between NOS understanding and students' CKE learning gain in group B as well, whereas the interaction effects between students' NOS understanding and their learning gain regarding NETC was found not significant for both groups ( $p = .20/.23$ ). As the descriptive statistics showed the same tendencies as in our original analyses, a higher sample size would likely lead to significant results taking the ratio score approach as well. However, due to the treatment of missing answers in the reported study and the subsequent limitations, the results should be interpreted with care and considered only as an indication for a potential correlation between NOS understanding and learning of energy content knowledge.

## 7 Conclusions and Implications

Overall, our study, aiming to shed more light on the interactions between NOS understanding and science content learning, may be summarized as follows:

- Regression-based analyses modeling NOS understanding as a covariate for energy understanding and energy learning provided evidence that NOS understanding is related to the learning of science content.
- In particular, NOS understanding seems to be of relevance to the learning of epistemological aspects of energy (understanding the nature of energy as a theoretical concept), as well as of the more advanced aspects of energy (like degradation).

With the present study, we were able to support the findings of Papadouris and Constantinou (2014) that NOS instruction might indeed help students learn to appreciate the epistemological aspects of energy and the nature of energy as a theoretical concept. Thus, in order to understand and value that energy—as all theoretical constructs—is “invented,” but can still be widely used to explain phenomena and make predictions, an understanding of what theories are and how the body of knowledge is built up and elaborated in science appears necessary. Papadouris and Constantinou's (2014) mostly descriptive analysis of the impact of a NOS-informed teaching unit could be reproduced using quantitative measures and inferential statistics. Furthermore, in our study, we extend the focus of this prior research by also investigating how the learning of non-epistemological disciplinary aspects of energy are related to students' NOS understanding.

Certainly, our findings also need to be substantiated and generalized by further research. This should focus on investigating the causal relation between NOS and energy learning in a rigid experimental setting employing an intervention study design. Based on our experiences, to maximize the possible effect of NOS on science content learning, such an intervention should (1) utilize a teaching approach that concatenates and integrates NOS aspects and content aspects of energy; (2) allow students to deal with NOS aspects for a longer period of time; and (3) focus on older students (who probably are already more familiar with the concept of energy and thus may be better able to also identify NOS-specific aspects within the concept of energy). Additionally, such a study should make use of instruments that are very well aligned with the teaching material, to detect even small gains in students' learning about NOS and energy.

Furthermore, more research is needed to investigate if the learning of scientific concepts other than energy benefits from an adequate NOS understanding and which concepts do so in particular. As we have seen in our study, the learning of some energy aspects did not seem to be closely related to students' NOS understanding, while others did. In particular, those aspects of energy that are more accessible to students (e.g., energy forms) seemed to be less related to NOS understanding than those that are more difficult to grasp and more related to everyday phenomena than to idealized systems as they are often included in school instruction (e.g., energy degradation). In consequence, scientific concepts that are similarly abstract (such as force or evolution) may benefit more from an adequate NOS understanding than those that are more accessible to students (such as mass or momentum). Overall, studies like this may help to identify the role of NOS for science content learning, and may ultimately help to generate ways to promote successful science teaching.

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**Conflict of interest** The authors declare no conflict of interest.

## Appendix

**Table 6** Reliability for the used assessment instruments

Variable	<i>n</i> (items)	Cronbach's alpha	
		Pretest	Posttest
Content knowledge on energy (CKE)	30	.75	.78
Nature of science understanding (NOS)	22	.67	.78
Understanding of nature of energy as a theoretical concept (NETC)	10	.64	.73
Motivation	7	.64	.73
Interest in physics	5	.70	-
Self-concept in physics	4	.80	-
Cognitive abilities	25	.89	-

**Table 7** Descriptive statistics for total sample

Variable	Number	Min	Max	Range	Mean	SD
NOS (pretest)	82	11	42	31	28.30	7.24
CKE (pretest)	82	3	26	23	11.62	4.94
CKE (posttest I (both groups))	82	7	36,5	29,5	20.12	5.69
CKE (posttest II (only group B))	40	6,5	36,5	30	22.35	6.28
NETC (pretest)	82	0	10	10	1.98	1.96
NETC (posttest)	82	0	13	13	4.46	3.49
Motivation (pretest)	81	2,5	5	2,5	4.07	0.60
Motivation (posttest)	81	3	5	2	4.25	0.59
Interest in physics	81	1,4	5	3,6	3.45	0.79
Self-concept in physics	73	1	4,25	3,25	2.12	0.90
Cognitive abilities	81	23	69	46	50.30	10.06

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