

NATURE OF SCIENCE
IM FACHKONTEXT PHYSIK

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ZUSAMMENFASSUNG

Neben der Vermittlung von Fachwissen wird – insbesondere im internationalen Kontext – viel darüber diskutiert, ob naturwissenschaftlicher Unterricht auch Vorstellungen über das Wesen, den Status und den Nutzen naturwissenschaftlichen Wissens vermitteln soll. In diesem Zusammenhang wird auch die Argumentation vorgebracht, ein Verständnis dieser unter „Nature of Science“ (NOS) zusammengefassten Aspekte könne das Verständnis naturwissenschaftlicher Konzepte befördern, indem es etwa eine bessere Einordnung neu erlernten Wissens in bereits Bekanntes ermöglicht oder das Interesse an den Naturwissenschaften steigert (Driver, Leach, Millar & Scott, 1996). Insbesondere wenn epistemologische Aspekte naturwissenschaftlichen Wissens als Teil konzeptuellen Verständnisses im Unterricht vermittelt werden sollen, scheint ein Zugang über NOS sinnvoll (Papadouris & Constantinou, 2017). Eine systematische empirische Untersuchung solcher Ansätze fand allerdings bisher kaum statt (Lederman, 2007; Peters, 2012).

Im Rahmen der vorliegenden Arbeit wird der mögliche Zusammenhang zwischen NOS-Verständnis und konzeptuellem Verständnis in den Naturwissenschaften von verschiedenen Seiten beleuchtet. Nach einem Überblick über das Themenfeld NOS und die Argumente, die für eine Thematisierung von NOS im Unterricht vorgebracht werden, werden vier zu diesem Promotionsprojekt zugehörige Publikationen vorgestellt. In der ersten dieser Publikationen wurde eine Synopse der bisherigen theoretischen Argumentation und der empirischen Untermauerung des lernpsychologischen Arguments (Driver et al., 1996) für eine Vermittlung von NOS erarbeitet. In einer darauf aufbauenden Interventionsstudie mit 82 Schülerinnen und Schülern der sechsten und siebten Jahrgangsstufe wurde zunächst der Zusammenhang zwischen NOS-Verständnis und der Entwicklung konzeptuellen Verständnisses während einer Einheit zum Energiekonzept untersucht (Publikation 2). Hierbei wurde zwischen Lernzuwächsen bzgl. fachlicher und epistemologischer Aspekte des Energiekonzepts unterschieden, wobei letztere nur implizit in der Unterrichtseinheit enthalten waren. Für eine zweite Studie wurden schließlich Aktivitäten entwickelt, in denen NOS-Aspekte und fachliche Aspekte des Energiekonzepts so miteinander verknüpft wurden, dass die epistemologischen Aspekte des Konzepts explizit thematisiert werden (Publikation 3). Die Wirkung einer entsprechenden integrierten Unterrichtseinheit wurde schließlich in einer zweiten Interventionsstudie mit 191 Schülerinnen und

Schülern der Oberstufe mit der Wirkung einer konventionellen Einheit zum Energiekonzept verglichen (Publikation 4).

In den Ergebnissen der Arbeit zeigt sich, dass die sinnvolle Begründung eines Zusammenhangs zwischen NOS-Verständnis und konzeptuellem Verständnis stark von der entsprechenden Konzeptualisierung abhängt. Werden über das Verständnis fachwissenschaftlicher Aspekte hinaus auch epistemologische Aspekte naturwissenschaftlicher Konzepte als Bestandteil konzeptuellen Verständnisses betrachtet (siehe Papadouris & Constantinou, 2017), kann ein NOS-orientierter Unterricht neue Perspektiven auf naturwissenschaftliche Konzepte wie Energie eröffnen, die sonst nur schwer zugänglich sind. Auch empirisch zeigt sich ein Zusammenhang zwischen NOS-Verständnis und Lernzuwachs bzgl. epistemologischer Aspekte des Energiekonzepts. Während sich einzelne epistemologische Aspekte (wie auch einzelne NOS-Aspekte) offenbar auch implizit vermitteln lassen, scheint ein explizit-reflektiver Ansatz hierfür deutlich effizienter.

ABSTRACT

Besides conveying an adequate understanding of science content knowledge, many scholars advocate that science education should also take views and beliefs about the nature, status, and value of scientific knowledge into account. In this context, Driver et al. (1996) argue that an understanding of this “nature of science” (NOS) could promote the learning of science content, for example by enabling students to make sense of newly acquired knowledge aspects and to integrate them into their conceptual understanding (“science learning argument”). If science education also takes into account epistemological aspects of science concepts as part of conceptual understanding, a NOS-oriented approach appears highly feasible (Papadouris & Constantinou, 2017). However, respective learning and teaching approaches have rarely been investigated empirically to date (Lederman, 2007; Peters, 2012).

In the dissertation at hand, the potential relation between NOS understanding and conceptual understanding in science is examined taking from different perspectives. After providing an overview on what constitutes NOS and which arguments are provided in the literature for an implementation of NOS in science teaching, four publications are presented, which are associated to this dissertation. The first of these publications presents a synopsis of the theoretical grounding and empirical substantiation of the science learning argument (Driver et al., 1996), which has been provided in the literature so far. Building on the findings, an intervention study with 82 middle school students was conducted to investigate the connection between NOS understanding and the development of conceptual understanding during a teaching unit on the energy concept (publication 2). To this end, learning gains regarding disciplinary content knowledge, as well as understanding of the epistemological aspects of energy (EAE), were examined, with the latter being only implicitly included in the teaching unit. Eventually, for a second empirical study, learning activities were designed that integrate both NOS and science content aspects in a way, in which they are thought to mutually promote each other, while at the same time explicitly focusing on EAE (publication 3). The effect of a respective integrated teaching unit – in comparison to a conventional unit on energy – was then investigated in an intervention study with 191 upper secondary school students (publication 4).

Overall, a meaningful argumentation for a relation between NOS understanding and conceptual understanding seems to substantially rely on the respective conceptualization of conceptual understanding itself. If, besides disciplinary aspects of science concepts, epistemological aspects are regarded as part of conceptual understanding as well (see Papadouris & Constantinou, 2017), a NOS-oriented teaching approach can open new perspectives on scientific concepts such as energy, which are otherwise hardly accessible. A relation between NOS understanding and learning gains regarding epistemological aspects of the energy concept can also be shown empirically. While certain epistemological aspects (just as certain NOS aspects) can be conveyed implicitly, an explicit-reflective approach seems considerably more efficient.

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1 EINLEITUNG

Der naturwissenschaftliche Unterricht steht insgesamt vor der Herausforderung, mit demselben Curriculum sowohl angehenden Studierenden naturwissenschaftlicher Fächer entsprechend anschlussfähige Methoden und Arbeitsweisen zu vermitteln, als auch zukünftigen Nicht-Naturwissenschaftlern im Sinne einer „scientific literacy“ (vgl. Roberts, 2007), also einer naturwissenschaftlichen Grundbildung, wichtige Konzepte und Charakteristika naturwissenschaftlichen Wissens nahezubringen, sowie wenn möglich dem sinkenden Interesse an Naturwissenschaften entgegenzuwirken (Driver et al., 1996). Roberts (2007) beschreibt in diesem Zusammenhang zwei „Visionen“ einer scientific literacy: Vision I strebt nach einer Grundbildung im Sinne eines Wissens um zentrale Aspekte und Prozesse *innerhalb* der Naturwissenschaften, während Vision II darüber hinaus auf die Befähigung zur Auseinandersetzung mit Situationen und Fragestellungen abzielt, die neben einem Verständnis naturwissenschaftlicher Konzepte auch andere Aspekte beinhalten. Im Sinne der Vision I ist ein wichtiges Ziel des naturwissenschaftlichen Unterrichts die Wissenschaftspropädeutik, also die direkte Vorbereitung späterer Studierender der Naturwissenschaften oder technischer Studiengänge (Höttecke, 2001a). Innerhalb der Unterrichtsfächer orientieren sich Ziele, Inhalte und Methoden – auch in Zeiten an Zielkompetenzen orientierter Standards und Kerncurricula – oft an der universitären Organisation der zugehörigen Fachdisziplinen (Rehm et al., 2008). Während in Präambeln und Einleitungen von Bildungsstandards und Curricula zwar auch weiterführende Bildungsziele im Sinne der Vision II einer scientific literacy (Roberts, 2007) beschrieben werden (z.B. Ministerium für Schule und Berufsbildung des Landes Schleswig-Holstein, 2016; Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen, 2008), werden diese innerhalb der Curricula kaum mit inhaltlichen Kompetenzzielen verknüpft (siehe hierzu Abschnitt 1.3). Die aus der Fachsystematik hervorgegangenen, auf Qualifizierung und Nachwuchsrekrutierung abzielenden Curricula schaffen es allerdings oft nur unzureichend, ein umfassendes und verständliches Bild der Disziplinen zu vermitteln:

In der Praxis heißt das v.a. für den Physikunterricht allgemeinbildender Schulen, dass die Lernenden sich mit Inhalten auseinandersetzen müssen, die sie selbst nur schwer mit Sinn besetzen können. Formeln und Gesetze muss man sich einverleiben. Ein sinnvoller Zusammenhang ist wenn überhaupt oft nur aus dem Kontext der Fachsystematik selbst zu beziehen, der sich allerdings nur jenen erschließen kann, die

schon einen Überblick über ihr Fach gewonnen haben. Das dürften bestenfalls nur die LehrerInnen selbst sein. (Höttecke, 2001a, S. 7)

Problematisch ist dies vor allem für diejenigen, die lediglich im Schulunterricht einen direkten Zugang zu den Naturwissenschaften erhalten und dort Vorstellungen vom epistemologischen Status der Wissensbestände und von den Verflechtungen der jeweiligen Disziplin mit Gesellschaft, Kultur, Religion, Ökonomie und anderen Bereichen des Lebens entwickeln, ohne später in Form eines naturwissenschaftlichen Studiums oder eines technischen Berufs weiter darauf einzugehen (Höttecke, 2001a). Sie nehmen implizit durch jede Art von Unterricht, Studium oder Medienkonsum Bilder und Vorstellungen über den Charakter der Naturwissenschaft und naturwissenschaftlichen Wissens, wie auch naturwissenschaftlicher Methoden, Gedanken und Einflussfaktoren auf, ohne diese jedoch in einen größeren Zusammenhang zu setzen und kritisch zu reflektieren (Clough, 2006; Höttecke, 2001a; Kircher & Dittmer, 2004):

Das Ergebnis sind Mythen über die Naturwissenschaft: Wissen erscheint als unveränderlich und wahr, anstatt als von Menschen in einem historischen Prozess hergestellt und kontingent. Motivationen zur Produktion des Wissens werden ausgeblendet, so dass der Eindruck der Wertfreiheit der Naturwissenschaften implizit vermittelt wird. Sollte doch einmal am Rande von den Entstehungsbedingungen die Rede sein, so werden sie auf Geschichten genialer und hochintelligenter Übermenschen (besser: Übermänner) reduziert. (Höttecke, 2001a, S. 7)

Ein solcher oft auf bloße Reproduktion fachlicher Inhalte beschränkter und an Lehrbüchern und Prüfungen orientierter Unterricht wird auch als verantwortlich für schwindende Motivation, Leistungsbereitschaft, sowie mangelndes Interesse an den Naturwissenschaften, insbesondere an der Physik, angesehen (Bell, Abd-El-Khalick, Lederman, McComas & Matthews, 2001; Clough, 2011; Driver et al., 1996; Kircher & Dittmer, 2004). Laut Höttecke (2001a) müssten für eine Vermittlung eines differenzierten Wissenschaftsverständnisses im Unterricht neben Fachwissenselementen wiederholt auch Eigenschaften und Charakteristika des Wesens der Naturwissenschaften, einer sogenannten „Nature of Science“ (NOS) fest im didaktisch-methodischen Unterrichtsrahmen verankert werden.

Vor allem im englischsprachigen Raum wird für ein an scientific literacy orientiertes Curriculum diskutiert, NOS im Fachunterricht explizit zu thematisieren (McComas & Olson, 1998; e.g. NGSS Lead States, 2013). Mit der Begründung dieser Herangehensweise, aber

auch mit den Möglichkeiten der Ausgestaltung und mit der Wirkung eines entsprechenden Unterrichts beschäftigt sich die vorliegende Arbeit. Als fachlicher Kontext wurde hierbei das Energiekonzept gewählt, da dieses ein zentrales Konzept in den Naturwissenschaften ist, mit welchem Schülerinnen und Schüler im Umgang immer wieder Schwierigkeiten zeigen (Neumann, Viering, Boone & Fischer, 2013). Zunächst wird ein Überblick über die in der Literatur vorgebrachten Argumente für eine Implementierung von NOS im naturwissenschaftlichen Unterricht gegeben und die schulisch als relevant erachteten Aspekte von NOS erläutert. In der darauffolgenden Darstellung der mit der Arbeit verknüpften Publikationen werden zunächst die möglichen Wirkmechanismen von NOS auf das konzeptuelle fachliche Verständnis, aber auch auf wichtige affektive, motivationale und kognitive Einflussfaktoren von Lernenden theoretisch genauer betrachtet. Anschließend wird die mögliche Ausgestaltung einer entsprechenden Einheit zum Energiekonzept präsentiert und die Ergebnisse zweier Interventionsstudien zu entsprechenden Unterrichtsversuchen in der Mittel- und Oberstufe werden berichtet. Schließlich werden die Ergebnisse der gesamten Arbeit diskutiert und Implikationen für die weitere fachdidaktische Forschung, wie auch für die Unterrichtspraxis abgeleitet.

1.1 NATURE OF SCIENCE ALS INHALT EINES ANSCHLUSSFÄHIGEN NATURWISSENSCHAFTSUNTERRICHTS

Nature of Science vereint soziologische, historische, epistemologische und methodologische Aspekte der Naturwissenschaften. Lederman, Abd-El-Khalick, Bell und Schwartz (2002) beschreiben NOS wie folgt: „Typically, NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development” (Lederman et al., 2002, S. 498). Eine ähnliche Definition liefert auch Clough (2006):

The phrase ‘nature of science’ (NOS) is often used in referring to issues such as what science is, how it works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society itself both influences and reacts to scientific endeavors. (Clough, 2006, S. 463)

Driver, Leach, Millar und Scott (1996) geben in einer Zusammenfassung in der Literatur gängiger Argumentationslinien für eine Thematisierung von NOS im Unterricht fünf Hauptargumente an:

<i>Das Nützlichkeitsargument</i>	<i>Ein Verständnis der Natur der Naturwissenschaften ist notwendig, wenn man Naturwissenschaften verstehen und technische Objekte und Prozesse handhaben und erledigen soll, die einem im täglichen Leben begegnen.</i>
<i>Das demokratische Argument</i>	<i>Man muss das Wesen der Naturwissenschaften verstehen, damit man gesellschaftlich-naturwissenschaftliche Probleme verstehen und an Entscheidungsprozessen teilnehmen kann.</i>
<i>Das kulturelle Argument</i>	<i>Ein solches Verständnis der Naturwissenschaften ist notwendig, um die Naturwissenschaften als ein wesentliches Element der gegenwärtigen Kultur zu schätzen.</i>
<i>Das moralische Argument</i>	<i>Es ist von allgemeinem sittlichem Wert, die Normen der naturwissenschaftlichen Gemeinschaft mit ihren moralischen Verpflichtungen zu verstehen</i>
<i>Das lernpsychologische Argument</i>	<i>Erfolgreiches Lernen der naturwissenschaftlichen Inhalte wird dadurch gefördert, dass darin auch die Natur der Naturwissenschaften als Inhalt eingeschlossen ist.</i>

(Driver et al., 1996; in der Übersetzung von Kircher & Dittmer, 2004, S. 2–3)

Lernende sollen durch eine Auseinandersetzung mit NOS im Unterricht eine kritische Haltung und eine gesunde Skepsis gegenüber den Naturwissenschaften einnehmen, die sie zu einer Verwertung naturwissenschaftlicher Erkenntnisse im täglichen Leben, zum eigenen Bewerten naturwissenschaftlicher Fragestellungen und Expertenmeinungen sowie zur Partizipation an gesamtgesellschaftlichen Entscheidungsprozessen befähigt (Abd-El-Khalick, 2012). Auch in einem wissenschaftspropädeutischen Sinne kann ein Verständnis von NOS helfen, Schülerinnen und Schüler an naturwissenschaftliche Studiengänge und technische Berufe heranzuführen und ihnen einen Überblick über innerdisziplinäre Prozesse, Arbeits- und Denkweisen geben (Peters-Burton, 2013). Im Sinne einer Betrachtung „epochaltypischer Schlüsselprobleme“ (Klafki, 2007) sind ebenfalls nicht nur die Naturwissenschaften und die Technik relevant, sondern auch deren Auswirkung auf Gesellschaft, auf Lebensstile und Weltbilder der Individuen (Kircher & Dittmer, 2004; Neumann, 2011).

Während die vier erstgenannten Argumente eher intrinsischer Natur sind und die Bedeutung von NOS als Unterrichtsinhalt für sich gesehen begründen, zielt das letztgenannte lernpsychologische Argument auf die Bedeutung von NOS für naturwissenschaftliche Lernprozesse im Allgemeinen. Um sinnvolle Zusammenhänge zwischen verschiedenen innerfachlichen Themenkomplexen herstellen zu können, schlagen Driver et al. (1996) vor, Schülerinnen und Schüler an eine reflektierte und kritische Sichtweise auf die Naturwissenschaften heranzuführen. Ein breiteres NOS-Verständnis könne Lernende demnach darin befördern, Fachinhalte in einen größeren Gesamtzusammenhang einzuordnen und somit Fachwissen strukturierter aufzunehmen. Lernende sollen dazu befähigt werden, die Genese naturwissenschaftlichen Wissens nachzuvollziehen und sich somit auch über die Natur dieses Wissens im Klaren zu sein (für eine ausführliche Betrachtung des lernpsychologischen Arguments, siehe Abschnitt 3.2).

1.2 KONZEPTUALISIERUNGEN UND INHALTE VON NATURE OF SCIENCE

Obwohl eine eindeutige Definition sowie eine genaue Abgrenzung von NOS gegenüber benachbarten Disziplinen umstritten sind und je nach Standpunkt verschiedene Bereiche als Bestandteil von NOS gesehen oder als eigenständige Bereiche deklariert werden (siehe z.B. Allchin, 2017; Dagher & Erduran, 2017; Hodson & Wong, 2017), herrscht im Kern eine große Übereinstimmung bzgl. der in unterschiedlichen Konzeptualisierungen berücksichtigten Aspekte (Neumann & Kremer, 2013). Ebenso gibt es breite Überschneidungen in verschiedenen internationalen Standarddokumenten und curricularen Rahmenvorgaben bezüglich der Aspekte von NOS, die für eine unterrichtliche Thematisierung als relevant angesehen werden (Lederman, 2007; McComas & Olson, 1998). Osborne, Collins, Ratcliffe, Millar und Duschl (2003) haben eine Delphi-Studie zu der Frage durchgeführt, welche „ideas-about-science“ im naturwissenschaftlichen Unterricht adressiert werden sollten. 23 Teilnehmende aus unterschiedlichen Fachrichtungen (Naturwissenschaftsdidaktiker, Wissenschaftler, Naturwissenschaftshistoriker, -philosophen und -soziologen, Experten in naturwissenschaftlicher Öffentlichkeitsarbeit, Naturwissenschaftslehrer) wurden gefragt, welche Ansichten über naturwissenschaftliche Methoden, naturwissenschaftliches Wissen und die Institutionen und sozialen Praktiken der Naturwissenschaften in der Schule vermittelt werden sollten. Nach mehreren Auswertungs- und Überarbeitungsrounds erhielten Osborne et al. schließlich neun Dimensionen von NOS,

die als besonders zentral für eine schulische Thematisierung angesehen wurden: (1) science and certainty, (2) analysis and interpretation of data, (3) scientific method and critical testing, (4) hypothesis and prediction, (5) creativity, science and questioning, (6) cooperation and collaboration in the development of scientific knowledge, (7) science and technology, (8) historical development of scientific knowledge und (9) diversity of scientific thinking (Osborne et al., 2003).

Lederman (2007) und Schwartz, Lederman und Lederman (2008) unterscheiden zwei miteinander in Beziehung stehende Bereiche von NOS – Nature of Scientific Knowledge (NOS) und Nature of Scientific Inquiry (NOSI). Lederman (2007) bezeichnet sieben Aspekte von NOS als wichtig für Schülerinnen und Schüler. Nach dieser Aufstellung sollten Lernende ein Verständnis von dem Unterschied (1) zwischen Beobachtungen und Schlussfolgerungen, sowie (2) zwischen naturwissenschaftlichen Gesetzen und Theorien haben und sollten außerdem wissen, dass naturwissenschaftliches Wissen (3) auf empirischen Daten basiert, (4) subjektiv und theoriegeleitet, (5) vorläufig und (6) soziokulturell eingebettet und beeinflusst ist und die Generierung solchen Wissens neben wissenschaftlicher Sorgfalt (7) Vorstellungskraft und Kreativität erfordert. Für NOSI beschreiben Schwartz, Lederman und Lederman (2008) weitere sieben für den Unterricht wichtige Aspekte: (1) questions guide investigations, (2) multiple methods of scientific investigations, (3) multiple purposes of scientific investigations, (4) justification of scientific knowledge, (5) recognition and handling of anomalous data, (6) sources, roles of, and distinctions between data and evidence und (7) community of practice (Schwartz et al., 2008, S. 4).

Kircher und Dittmer (2004) sehen in diesem Zusammenhang auch ethische Aspekte, sowie eine Bildung der Nachhaltigkeit als wichtige Bestandteile einer erweiterten naturwissenschaftlichen Grundbildung. Weitere, zumeist ebenfalls breiter gefasste Ansätze zur Konzeptualisierung von NOS für den Unterricht finden sich etwa bei Allchin (2017), Dagher und Erduran (2017) oder Hodson und Wong (2017). Bei dem mit NOS nah verwandten Konzept der epistemologischen Überzeugungen, welches vor allem im Bereich der Kognitionspsychologie und der pädagogischen Psychologie betrachtet wird, werden zudem noch Vorstellungen über das eigene Lernen mit einbezogen (Hofer & Pintrich, 2002; siehe auch Neumann & Kremer, 2013). Obwohl sich also verschiedene Aufstellun-

gen wichtiger NOS-Aspekte formulieren lassen, sind die einzelnen Aspekte dieser Nennungen nie voneinander gänzlich unabhängige Konstrukte, sondern sind auf vielfältige Art und Weise miteinander verknüpft (Peters-Burton, 2013). Und auch die unterschiedlichen Konzeptualisierungen haben trotz einzelner Unterschiede eine starke gemeinsame Grundlage. Im Kontext dieser Arbeit wurde bei der Entwicklung der Unterrichtsmaterialien für die Interventionsstudien, wie auch bei der Auswahl entsprechender Testinstrumente die oben beschriebene (und in der Forschungsliteratur viel genutzte) Konzeptualisierung von Lederman (2007) zu Grunde gelegt, wobei zumeist nicht alle sieben genannten Aspekte, sondern eine entsprechende Auswahl genutzt wurde.

1.3 NOS IN STANDARDS UND CURRICULA

International berücksichtigen verschiedene Standarddokumente und curriculare Rahmenseitlungen NOS als Bestandteil des naturwissenschaftlichen Unterrichts (McComas & Olson, 1998). So weisen etwa die US-amerikanischen „National Science Education Standards“ (National Research Council, 1996), die „Benchmarks for science literacy“ (AAAS, 1993) und auch die neu entwickelten „Next Generation Science Standards“ (NGSS Lead States, 2013) explizite Abschnitte über NOS auf. In den deutschen Bildungsstandards (KMK, 2005b), wie auch in den Kerncurricula und Fachanforderungen der Bundesländer (z.B. Ministerium für Schule und Berufsbildung des Landes Schleswig-Holstein, 2016; Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen, 2008), werden Aspekte von NOS nur sehr vereinzelt angesprochen (Neumann, 2011). Formulierungen, die zumindest implizit NOS-Aspekte enthalten, finden sich in den Bildungsstandards für das Fach Physik mit der Forderung, dass Schülerinnen und Schüler „die Gültigkeit empirischer Ergebnisse und deren Verallgemeinerung beurteilen“ können sollten (KMK, 2005b, S. 11). Im einleitenden Abschnitt werden als Ziele eines physikalischen Unterrichts unter anderem die Förderung für das Fach typischer Herangehensweisen an Aufgaben und Probleme sowie die Entwicklung einer spezifischen Weltansicht benannt (KMK, 2005b). In den Vorbemerkungen der Fachanforderungen Physik für das Gymnasium in Schleswig-Holstein finden sich weitere Bezüge auf Wesen und Wert naturwissenschaftlichen Wissens:

Naturwissenschaftliche Erkenntnisse stellen eine bedeutende kulturelle Errungenschaft dar und prägen maßgeblich viele Bereiche unserer Gesellschaft. Die naturwissenschaftlich-technische Entwicklung birgt

Chancen und Risiken, für deren Bewertung ein Verständnis der Physik, ihrer zentralen Theorien und Erkenntnisse sowie der typischen Arbeitsmethoden und Denkstrukturen unverzichtbar ist. Der Physikunterricht leistet damit einen wesentlichen Beitrag zur Allgemeinbildung. (Ministerium für Schule und Berufsbildung des Landes Schleswig-Holstein, 2016, S. 12)

Vor allem im Bereich der Modellierung wird außerdem die Vorläufigkeit und Veränderlichkeit naturwissenschaftlicher Theorien angesprochen:

Die Modellierung physikalischer Sachverhalte spielt eine zentrale Rolle im Physikunterricht. Modelle erlauben es, das Verhalten physikalischer Systeme auf der Grundlage physikalischer Theorien zu beschreiben und vorherzusagen. Bestätigen sich die Vorhersagen, stützt dies die Theorie. Bestätigen sich die Vorhersagen nicht, ist die Theorie anzupassen. Modelle sind damit ein wesentliches Element bei der Entwicklung beziehungsweise Weiterentwicklung physikalischer Theorien. Sie sind weder wahr noch falsch, sondern stellen physikalische Sachverhalte mehr oder weniger differenziert dar. (Ministerium für Schule und Berufsbildung des Landes Schleswig-Holstein, 2016, S. 14)

Ähnliche Formulierungen finden sich auch in den Curricula anderer Bundesländer (z.B. Kernlehrplan Physik für das Gymnasium in Nordrhein-Westfalen):

Gemäß den Bildungsstandards ist es Ziel dieser naturwissenschaftlichen Grundbildung, wichtige Phänomene in Natur und Technik zu kennen, Prozesse und Zusammenhänge zu durchschauen, die Sprache und Geschichte der naturwissenschaftlichen Fächer zu verstehen, ihre Erkenntnisse zu kommunizieren sowie sich mit ihren spezifischen Methoden der Erkenntnisgewinnung und deren Grenzen auseinanderzusetzen. (Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen, 2008, S. 8)

Auch in der Ausformulierung der prozessbezogenen Kompetenzen, die im Physikunterricht im Laufe der Sekundarstufe I und II entwickelt werden sollen, finden sich einige Aspekte, die eng mit NOS verknüpft sind. So sollen im Unterricht der Sekundarstufe I in Schleswig-Holstein etwa folgende Kompetenzen gefördert werden:

Die Schülerinnen und Schüler...

...trennen zwischen den Beobachtungen sowie den aufbereiteten Daten und deren Deutung.

...beurteilen die Gültigkeit empirischer Ergebnisse und deren Verallgemeinerung.

...beurteilen und bewerten an ausgewählten Beispielen empirische Ergebnisse und Modelle kritisch auch hinsichtlich ihrer Tragweiten und Grenzen.

...beschreiben (historische) Einflüsse auf Entwicklungen und Veränderungen physikalischer Erkenntnisse.

...beurteilen die Aussagekraft empirischer Ergebnisse für wissenschaftliche Entwicklungen.

(Ministerium für Schule und Berufsbildung des Landes Schleswig-Holstein, 2016, 17 f.)

Für die Sekundarstufe II kommen außerdem folgende Zielkompetenzen hinzu:

Die Schülerinnen und Schüler...

...beschreiben Genese und Leistungsfähigkeit von physikalischen Theorien.

...reflektieren Auswirkungen physikalischer Erkenntnisse sowie eigenen und fremden Handelns in historischen und gesellschaftlichen Zusammenhängen.

(Ministerium für Schule und Berufsbildung des Landes Schleswig-Holstein, 2016, 43 ff.)

Diese prozessbezogenen Kompetenzen werden allerdings nicht explizit mit den inhaltsbezogenen Kompetenzen und entsprechenden Lernzielen verknüpft. NOS-Aspekte sind überdies weder in den inhaltsbezogenen Kompetenzen der Sekundarstufe I noch der Sekundarstufe II enthalten. Insofern ist fraglich, inwieweit sie tatsächlich Einzug in den Unterrichtsalltag halten.

Obwohl NOS in internationalen Curricula durchaus explizit Erwähnung findet, wird der Bereich von Lehrerinnen und Lehrern auch dort oft nicht oder nur unzureichend unterrichtet (Abd-El-Khalick, Bell & Lederman, 1998; Bell, Lederman & Abd-El-Khalick,

2000; Clough, 2006). Kircher und Dittmer (2004) nennen hierfür als Gründe die Komplexität, die prinzipielle Vorläufigkeit und die geringe Vertrautheit der Lehrerinnen und Lehrer mit der Thematik, auch durch das Fehlen von NOS-Inhalten in der Ausbildung naturwissenschaftlicher Lehrkräfte. Viele Lehrende befürchten außerdem, eine Thematisierung wissenschaftsphilosophischer und -historischer Gesichtspunkte im Unterricht könne viel Zeit in Anspruch nehmen, die dann für ihre „eigentliche Aufgabe“ (die Vermittlung des in Standards und Curricula festgeschriebenen Fachwissens) fehlen würde (Clough, 2006). Die Vermittlung eines NOS-Verständnisses bei Schülerinnen und Schülern erfolgt aber unabhängig von einer expliziten Thematisierung. Durch die Verwendung naturwissenschaftlicher Begriffe seitens des Lehrers, durch kochrezeptartige Experimente, Schulbücher, die naturwissenschaftliche Wissen darstellen, ohne auf dessen Entstehungsgeschichte und Charakteristika einzugehen, sowie durch Medieneinfluss und Alltagserfahrungen erhalten Schülerinnen und Schüler ein Bild von NOS, unabhängig davon, ob dieses explizit oder implizit vermittelt wird (Clough, 2006; Driver et al., 1996). Ein implizit und un gelenkt vermitteltes NOS-Verständnis ist allerdings zumeist unreflektiert und naiv und kann nicht in gleicher Weise zur begründeten Meinungsbildung beitragen wie ein Curriculum, das Vorstellungen über Wissen und Wissenserwerb explizit zur Diskussion stellt (Urhahne & Hopf, 2004).

1.4 ERGEBNISSE BISHERIGER UNTERSUCHUNGEN ZUR AUSGESTALTUNG VON NOS IM UNTERRICHT

Verschiedene internationale Studien zeigen, dass Schülerinnen und Schüler aller Altersstufen, wie auch Lehrerinnen und Lehrer nach wie vor zumeist inadäquate und naive Vorstellungen von NOS haben (Abd-El-Khalick & Lederman, 2000; Dogan & Abd-El-Khalick, 2008; Höttecke, 2001b; Höttecke, 2004; Ibrahim, Buffler & Lubben, 2009; Khishfe & Abd-El-Khalick, 2002). Lehrerinnen und Lehrer, selbst wenn sie ein akkurates NOS-Verständnis vorweisen können, schaffen es darüber hinaus oft nicht, diese Ideen sinnvoll in den Unterricht einzubetten (Abd-El-Khalick et al., 1998; Abd-El-Khalick & Akerson, 2004; Bell et al., 2000). Schülerinnen und Schüler können bei entsprechender Instruktion bereits ab einem Alter von fünf Jahren bestimmte NOS-Aspekte konzeptualisieren, mit steigendem Alter geschieht diese Konzeptualisierung schneller und gerichteter (Akerson, Buck, Donnelly, Nargund-Joshi & Weiland, 2011). Dabei scheinen Aspekte

wie der Unterschied zwischen Beobachtungen und Schlussfolgerungen, der kreative Aspekt naturwissenschaftlicher Erkenntnisprozesse und die Vorläufigkeit und empirische Basis naturwissenschaftlichen Wissens jungen Lernenden zugänglicher zu sein als Subjektivität und soziokulturelle Einflüsse auf den Wissenschaftsprozess (Akerson, Weiland, Pongsanon & Nargund, 2010). Akerson et al. (2010) schlagen daher vor, Schülerinnen und Schülern zunächst die zugänglicheren Aspekte von NOS zu vermitteln und langfristig in Richtung der abstrakteren Charakteristika zu zielen.

Ein Ansatz für eine Vermittlung von NOS im Unterricht, bei dem ein adäquates Bild der Naturwissenschaften und naturwissenschaftlicher Denk- und Arbeitsweisen durch eigenes Experimentieren und die Betrachtung einzelner, ausgewählter wissenschaftlicher Persönlichkeiten *implizit* vermittelt werden soll, hat sich als weniger erfolgreich erwiesen (Khishfe & Abd-El-Khalick, 2002). Des Weiteren birgt dieser Ansatz die Gefahr, dass Schülerinnen und Schüler neben dem Wissenschaftsbild, welches sie bereits aus Alltagserfahrungen und Medien in den Unterricht mitbringen, ein zweites, paralleles, auf Schulwissen bezogenes Wissenschaftsbild aufbauen, da sie ihr eigenes wissenschaftlichen Vorgehen nicht als authentisch wahrnehmen und somit nicht mit dem Vorgehen „wirklicher“ Wissenschaftler verknüpfen (Clough, 2006; Solomon, 1991). Clough (2006) schreibt hierzu:

“Humans, by their very nature, make sense of experience in light of what they already know. Toward this end, learners attend to aspects of phenomena and other information that fit prior ideas, often unconsciously ignore contrary information, and sometimes modify incoming information so that it also fits what is already known. For this and other reasons, implicit NOS instruction designed to confront students’ deep misconceptions regarding the NOS are seemingly interpreted by students, often with little or no difficulty, to fit with their misconceptions, and thus does not result in dissatisfaction with prior ideas.” (Clough, 2006, S. 469)

Um tatsächlich einen inneren Konflikt im Denken der Lernenden auszulösen und sie dazu zu bringen, ihr eigenes NOS-Verständnis kritisch zu überdenken, ist vielmehr ein *explizit-reflektiver* Ansatz zu wählen, welcher so angelegt ist, dass die Aufmerksamkeit der Schülerinnen und Schülern direkt auf wichtige NOS-Aspekte gelenkt und diese bewusst und kritisch distanziert thematisiert werden (Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick & Lederman, 2000; Bell et al., 2000; Clough, 1997; Clough, 2006;

Khishfe & Abd-El-Khalick, 2002; Kircher & Dittmer, 2004; Lederman, 2007; McComas, 1998). Dies lässt sich etwa dadurch verwirklichen, dass Schülerinnen und Schülern vor dem eigenen wissenschaftlichen Vorgehen NOS-Aspekte explizit dargestellt und diese mit ihnen diskutiert werden. Wichtig sind auch eine abschließende Reflexion und Diskussion der eigenen Vorgehensweise und eine Sicherung der NOS-Aspekte am Ende der Lerneinheit (Akerson et al., 2010; Schwartz & Crawford, 2006).

Eine Möglichkeit, NOS explizit zu thematisieren, sind generische „NOS activities“ (Lederman & Abd-El-Khalick, 1998), die bestimmte NOS-Aspekte zunächst losgelöst von naturwissenschaftlichen Fachinhalten verdeutlichen. Solche dekontextualisierten Aktivitäten können allerdings von Schülerinnen und Schülern als nicht authentisch wahrgenommen werden, da sie nicht deren Bild vom Vorgehen „wirklicher“ Wissenschaftlerinnen und Wissenschaftler entsprechen. Dies kann zum oben beschriebenen Problem zweier paralleler NOS-Verständnisse führen (Clough, 2006). Des Weiteren nehmen Lehrerinnen und Lehrer dekontextualisierte NOS-Aktivitäten z.T. als „add-ons“ wahr, welche im Unterricht Zeit kosten, die dann zur Erarbeitung wichtiger Fachinhalte fehlt (Abd-El-Khalick et al., 1998; Lakin & Wellington, 1994). Um einen authentischen Zugang zu schaffen und zeitökonomischen Kriterien besser gerecht zu werden, sollte Unterricht über NOS daher kontextualisiert erfolgen (Brickhouse, Dagher, Letts & Shipman, 2000; Clough, 2006; Driver et al., 1996; Schwartz & Crawford, 2006). Auch Lederman und Abd-El-Khalick (1998) legen für einen größtmöglichen Lernerfolg eine entsprechende Einbettung ihrer „NOS activities“ in einen fachlichen Kontext nahe. Ziel ist es dabei, NOS-Aspekte und Fachkontext so nahtlos miteinander zu verweben, dass Lernende den Bezug zwischen ihren eigenen Erfahrungen und naturwissenschaftlichen Denk- und Arbeitsweisen selbstständig herstellen, und das Unterrichtsszenario nicht mehr als unauthentisch wahrnehmen. Für Lehrende wird damit eine NOS-Implementierung ebenfalls attraktiver, da die Erreichung zusätzlicher Lernziele und der authentische Zugang zu wissenschaftlichen Themen den Zeitaufwand der NOS-Thematisierung aufwiegen können (Clough, 2006; Clough & Olson, 2008). Für eine Einführung wichtiger NOS-Aspekte eignen sich dekontextualisierte „NOS activities“ oder das Lesen von Texten mit expliziter NOS-Thematisierung durchaus, da sie NOS-Inhalte in motivierender, konkreter Art vermitteln, ohne die Lernenden gleichzeitig mit weiteren fachlichen Aspekten zu überfrachten. Bei gleichzeitiger Einführung von NOS-Aspekten und neuen Fachinhalten zeigen einige Schülerinnen und Schüler Verständnisprobleme (Leach, Hind & Ryder, 2003), die

eine vorherige losgelöste Einführung von NOS möglicherweise vermindern kann (Clough, 2006). Gerade für jüngere Schülerinnen und Schüler kann so eine vorsichtige Heranführung an das abstrakte Thema NOS erfolgen, welches dann später im Rahmen von offenem oder geleitetem Experimentieren, durch Klassendiskussionen oder Hands-On-Activities vertieft und mit Fachinhalten verknüpft wird. Ergebnisse empirischer Studien zeigen dabei, dass NOS nicht nur im Sinne einer einzelnen Einheit im Rahmen eines Curriculums vermittelt werden sollte, sondern vielmehr als inhaltsübergreifender Aspekt an verschiedenen Stellen der Lehrpläne in Fachkontexte eingebettet werden sollte, um dauerhaft ein adäquates NOS-Verständnis zu vermitteln (Clough, 1997; Clough, 2006; Leach et al., 2003; Lederman, 2007; Schwartz, 2013). Auch Kircher und Dittmer (2004) schlagen eine Implementierung von NOS als naturwissenschaftliches Spiralcurriculum vor. Um die Übertragung des eigenen Vorgehens auf jenes „authentischer“ Wissenschaftler zu erleichtern, können historische oder aktuelle naturwissenschaftliche Fallstudien oder Experimente thematisiert und auf ihre Repräsentation bestimmter NOS-Inhalte hin untersucht und diskutiert werden (Akerson et al., 2010; Clough, 2006). Die Rolle des Lehrers in einem solchen Unterrichtsetting ist vor allem die Moderation und Thematisierung der Ähnlichkeiten und Unterschiede zwischen dem unterrichtlichen experimentellen Handeln, historischen bzw. modernen wissenschaftlichen Vorgehensweisen, oder dekontextualisierten NOS-Aktivitäten (Clough, 2006).

1.5 NOS UND PHYSIKLERNEN

Die für eine Implementierung von NOS in den naturwissenschaftlichen Unterricht genannten Argumente gelten in besonderem Maße für die Physik. Duit (2010) weist etwa auf die besonderen Herausforderungen des Modellbegriffs in der Physik hin. Lernschwierigkeiten, etwa beim Erlernen des Teilchenmodells, begründen sich demnach auch aus den „vagen und unscharfen Vorstellungen davon [...], was die Rolle eines Modells in der Physik ist“ (Duit, 2010, S. 3). Mathematische Modelle, wie sie in der Physik häufig Anwendung finden, sind mit die abstraktesten, gleichzeitig aber auch vorhersagekräftigsten Modelle in den Naturwissenschaften (Harrison & Treagust, 2000). Auch theoretische Modelle, wie etwa Magnetfeldlinien, eignen sich gut zur Erklärung naturwissenschaftlicher Phänomene, werden von Schülerinnen und Schülern aber oft als manifest missverstanden (Harrison & Treagust, 2000; Papadouris & Constantinou, 2017). Für ein Verständnis der

menschlich konstruierten Natur solcher Modelle und eine daraus folgende korrekte Nutzung sind multiple Konzeptwechsel notwendig, zum einen auf der Ebene der physikalischen Begriffe und Prinzipien, zum anderen aber auch auf der Ebene der Vorstellungen *über* Physik (Duit, 2010).

Die starke und für Lernende zum Teil undurchsichtige Abstraktheit ist laut Duit (1997) auch mitverantwortlich für das im Vergleich zur Biologie stark sinkende Interesse von Schülerinnen und Schülern an Physik im Laufe der Schulstufen 5 bis 10 und die damit verbundene Kurswahl für die Oberstufe. Duit (1997) führt diesen Abfall an Fachinteresse vor allem auf ein mangelndes Vertrauen in die eigene Leistungsfähigkeit in den betreffenden Fächern zurück, was auch in einem naiven NOS-Verständnis begründet sein kann. Allzu oft wird naturwissenschaftliches Wissen in der Schule als „wahr“ und unzweifelhaft angenommen (Höttecke, 2001b; McComas, 1996). Wissenschaftler gelten als geniale, hochintelligente und unsoziale Entitäten, die sich selbstständig komplizierte Experimente überlegen, mit denen sie für „Durchschnitts“-Menschen unbegreifliche Zusammenhänge „entdecken“ (Höttecke, 2004). Ein solches Wissenschaftsverständnis führt dazu, dass Schülerinnen und Schüler sich gegenüber Naturwissenschaftlern als „dumm und minderwertig“ fühlen (Höttecke, 2001a, S. 72), also ein negatives fachspezifisches Selbstkonzept entwickeln. Ein adäquates Verständnis der Charakteristika naturwissenschaftlichen Wissens und naturwissenschaftlicher Erkenntnisprozesse, einer „Nature of Science“¹ soll diesem Phänomen entgegenwirken, indem parallel zum Lernen begrifflicher und methodischer Strukturen der Naturwissenschaften adäquate erkenntnis- und wissenschaftstheoretische Vorstellungen vermittelt werden (Clough, 2006; Driver et al., 1996; Kircher & Dittmer, 2004; Lederman, 2007). Eine höhere Transparenz bezüglich der Genese und der Eigenschaften naturwissenschaftlichen Wissens könnte dabei helfen, das Interesse an den Naturwissenschaften hoch zu halten und im Physikunterricht das physikalische Selbstkonzept der Schülerinnen und Schüler zu fördern (Clough, 2011; Driver et al., 1996; McComas, Almazroa & Clough, 1998). Ebenso könnte das Interesse von Schülerinnen und Schülern an Physik davon profitieren, Naturwissenschaften als sozialen und gesellschaftlichen Prozess zu vermitteln, welcher die Arbeit mit Menschen und zum Nutzen anderer einschließt (Clough, 2011; Duit, 1997). Naturwissenschaften bekämen so

¹ Zur Diskussion, ob es sich tatsächlich um *eine* Nature of Science handelt, ob es entsprechend der verschiedenen naturwissenschaftlichen Disziplinen mehrere Konstrukte geben muss und ob sich der Begriff überhaupt zielsicher definieren lässt, siehe etwa die Stellungnahmen von Alters (1997b), Smith, Lederman, Bell, McComas, and Clough (1997) sowie Eflin, Glennan, and Reisch (1999).

ein menschlicheres Gesicht und können als gesamtgesellschaftliche Unternehmung wahrgenommen werden, anstatt als bloße Ansammlung auswendig zu lernender Fakten (McComas et al., 1998). Durch das Nachvollziehen historischer Erkenntnisprozesse können Schülerinnen und Schüler erkennen, dass ihre eigenen Fragen und Probleme mitunter auch diejenigen in der Geschichte der Naturwissenschaften gewesen sind, was zu einer Stärkung ihres Selbstkonzepts beitragen kann (Höttecke, 2001a).

Wie in den vorherigen Abschnitten dargestellt, gibt es eine große Bandbreite an Studien, die sich mit einer gewinnbringenden Vermittlung von NOS im Unterricht beschäftigt haben. Zumeist wurde hierbei allerdings die Wirkung eines solchen Unterrichts auf das NOS-Verständnis der Lernenden untersucht. Für das eingangs genannte lernpsychologische Argument, dass ein solches NOS-Verständnis Lernenden die Einordnung von Fachinhalten in einen umfassenderen Gesamtzusammenhang erleichtern und somit zu einem besseren Erlernen von Fachwissen und schließlich zu einem besseren Verständnis naturwissenschaftlicher Konzepte führen könnte, gibt es bislang noch wenig empirische Evidenz (Kircher et al., 2004; Peters, 2012), die zudem in ihren Ergebnissen sehr ambivalent ist (für eine ausführliche Betrachtung des Forschungsstands zu diesem Zusammenhang siehe Abschnitt 3.5). Eine weitere Klärung des lernpsychologischen Arguments nach Driver et al. (1996) steht also noch aus. Eine Bestätigung dieses Zusammenhangs hätte weitreichende Folgen für die Unterrichtspraxis, sowohl auf der Ebene der Elementarisierung und der didaktischen Rekonstruktion von Erkenntnis- und Wissenschaftstheorien, als auch auf den Ebenen der Curriculumentwicklung und empirischer Untersuchungen (Kircher & Dittmer, 2004). Eine empirische Untermauerung des lernpsychologischen Arguments könnte auch helfen, Lehrerinnen und Lehrern den Sinn einer NOS-Thematisierung im Unterricht weiter näherzubringen. Eine erfolgreiche Implementierung von NOS in physikalische Fachkontexte, die sowohl das Verständnis von NOS, als auch des betrachteten Fachinhalts fördert, könnte zeitökonomische Argumente gegen eine unterrichtliche Einbettung von NOS-Aspekten teilweise entkräften (Clough, 2006).

Als beispielhafter fachlicher Kontext für die im Rahmen des hier vorgestellten Promotionsprojekts durchgeführten Studien wurde das Energiekonzept gewählt, da dieses einerseits ein zentrales Konzept der Naturwissenschaften und Basiskonzept in den Bildungsstandards für Physik und Chemie ist (KMK, 2005a; KMK, 2005b), andererseits aber

Schülerinnen und Schülern immer wieder Verständnisprobleme bereitet (Driver & Warrington, 1985; Duit, 2014; Neumann et al., 2013; Nordine, Krajcik & Fortus, 2011). Dies liegt nicht zuletzt daran, dass Schülerinnen und Schüler Energie oft als etwas Stoffliches oder als eine Art Treibstoff begreifen (Duit, 1987; 2014; Warren, 2007) und dabei die eher theoretische, mathematische Natur des Konzepts verkennen (siehe z.B. Feynman, Leighton & Sands, 1963). Papadouris und Constantinou (2011) schlagen in diesem Zusammenhang vor, neben fachlichen Aspekten des Energiekonzepts (Energieformen, -transfer, -erhaltung und -entwertung, s. Duit, 2014) auch epistemologische Aspekte wie das theoretische, abstrakte Wesen von Energie, die disziplinübergreifende Bedeutung des Konzepts („crosscutting nature“) oder die Nützlichkeit bei dem Erklären und Vorhersagen natürlicher Phänomene zu betrachten (siehe Abschnitte 4.2 und 6.2). In der vorliegenden Arbeit wird die mögliche Wirkung von NOS sowohl auf fachliche, als auch auf epistemologische Aspekte des Energiekonzepts untersucht.

2 ZIELSETZUNG DER ARBEIT UND KONZEPTION DER STUDIEN

Im Rahmen dieser Dissertation werden theoretische Betrachtungen und empirische Ergebnisse aus vier zugehörigen Publikationen vorgestellt, zueinander in Zusammenhang gesetzt und diskutiert. Im Kern des entsprechenden Promotionsprojekts steht dabei das in Abschnitt 1.1 vorgestellte lernpsychologische Argument nach Driver, Leach, Millar und Scott (1996), nach dem ein adäquates Verständnis von NOS fachliche Lernprozesse und das Erlangen konzeptuellen Verständnisses in den Naturwissenschaften befördern könne. Vor diesem Hintergrund befasst sich die Arbeit mit folgenden zentralen Fragestellungen:

- (1) Inwieweit wird ein Zusammenhang zwischen NOS-Verständnis und konzeptuellem Verständnis in den Naturwissenschaften (wie durch Driver et al., 1996, angenommen) durch theoretische und empirische Erkenntnisse gestützt und welches sind die zu Grunde liegenden Mechanismen?
- (2) Wie wirkt sich das NOS-Verständnis von Schülerinnen und Schülern auf Lernprozesse bzgl. fachlicher und epistemologischer Aspekte während einer Unterrichtseinheit zum Energiekonzept aus?
- (3) Wie wirkt sich eine explizite, mit NOS-Aspekten verknüpfte Vermittlung epistemologischer Aspekte des Energiekonzepts auf entsprechende Lernprozesse aus, verglichen mit einer impliziten Vermittlung?

Ansatzpunkt der Arbeit ist zunächst eine ausführliche Betrachtung der theoretischen Grundlage und der empirischen Evidenz zu diesem Zusammenhang, auch unter der Perspektive neuerer Studien und Überlegungen zu diesem mittlerweile vor über zwanzig Jahren formulierten Argument. Die Publikation der hierfür erstellten Synopse und der folgenden theoretischen Diskussion erfolgte chronologisch nach der Publikation der Ergebnisse der ersten empirischen Studie, wird in dieser Arbeit aber vorangestellt, da die dahinterstehenden Überlegungen bereits in die Konzeption dieser ersten Studie eingeflossen sind.

Nach der Betrachtung und kritischen Diskussion des Forschungsstandes in Publikation 1 folgt in Publikation 2 die Darstellung der Konzeption und Ergebnisse einer empirischen Studie, in der untersucht wurde, inwieweit ein Verständnis von NOS den Lernzuwachs

bzgl. fachlicher und epistemologischer Aspekte während eines dreitägigen Ferienkurses beeinflusst. Als fachlicher Inhalt des Kurses wurde das aus den in Abschnitt 1.5 genannten Gründen das Energiekonzept gewählt. Die von Papadouris und Constantinou (2011) vorgeschlagenen epistemologische Aspekte wurden im Rahmen der ersten Studie als „nature of energy as a scientific concept“ mit erhoben. Das Alter der Stichprobe (82 Schülerinnen und Schülern der sechsten und siebten Jahrgangsstufe) wurde dabei so gewählt, dass möglichst noch keine Auseinandersetzung mit dem Energiekonzept im Rahmen des schulischen Unterrichts stattgefunden hat und die zu erwartenden Lernfortschritte somit möglichst groß sind. Insgesamt zeigten sich Hinweise auf einen möglichen Zusammenhang zwischen dem NOS-Verständnis der Schülerinnen und Schüler vor der Einheit und ihrem Lernzuwachs, vor allem im Bereich der epistemologischen Aspekte des Energiekonzepts. Allerdings konnte die in einem quasi-experimentellen Design angelegte Studie nicht entsprechend ausgewertet werden, da sich die beiden betrachteten Gruppen vor Eintritt in die Unterrichtseinheit zu Energie nicht (wie geplant) in ihrem NOS-Verständnis unterschieden (siehe Abschnitt 2.2). Auf Individualebene gab es allerdings eine ausreichende Varianz, so dass entsprechende Varianzanalysen durchgeführt werden konnten.

Ausgehend von diesen Ergebnissen wurde in einer zweiten Studie die Wirkung einer integrierten Unterrichtseinheit zum Energiekonzept gegenüber einer konventionellen Unterrichtseinheit untersucht. Im Gegensatz zur ersten Studie wurden hierfür NOS-Aspekte, sowie fachliche und epistemologische Aspekte des Energiekonzepts in entsprechenden Aktivitäten explizit miteinander verknüpft, um Schülerinnen und Schülern ein umfassendes Verständnis des Energiekonzepts, seiner fachlichen und epistemologischen Aspekte, sowie ein Verständnis von NOS zu vermitteln. Einzelne in diesem Zusammenhang entwickelte bzw. abgewandelte Aktivitäten wurden in einer praxisorientierten Zeitschrift veröffentlicht (Publikation 3).

Bei Durchführung einer entsprechenden Interventionsstudie wurden auch die Erfahrungen der ersten Studie mit einbezogen, woraus sich etwa Anpassungen bei der Jahrgangsstufe, Interventionsmaterial und verwendeten Testinstrumenten ergaben (siehe Abschnitt 2.4). Die integrierte Unterrichtseinheit wurde in einer quasi-experimentellen Studie mit 94 Schülerinnen und Schülern der Oberstufe im Rahmen eines zweitägigen Projektkurses implementiert. Als Kontrollgruppe dienten 97 Schülerinnen und Schüler, die ebenfalls

eine zweitägige Unterrichtseinheit zum Energiekonzept erhielten, allerdings ohne expliziten Bezug zu NOS oder epistemologischen Aspekten des Energiekonzepts. Der Lernzuwachs bzgl. des Fachwissens im Bereich des Energiekonzepts war bei beiden Gruppen vergleichbar. Sowohl bei der Entwicklung eines adäquateren NOS-Verständnisses als auch bei der Entwicklung eines Verständnisses der epistemologischen Aspekte von Energie war die Treatmentgruppe allerdings der Kontrollgruppe überlegen. Konzeption, Ergebnisse und Implikationen dieser Studie werden in Publikation 4 vorgestellt.

2.1 PUBLIKATION 1: HOW DOES NOS UNDERSTANDING CONNECT TO CONCEPTUAL UNDERSTANDING? THEORETICAL CONSIDERATIONS

Driver, Leach, Millar und Scott liefern in ihrem Werk „Young people’s images of science“ (Driver et al., 1996) eine umfassende Übersicht über die zum Zeitpunkt des Erscheinens verfügbare Literatur zum Themenfeld Nature of Science. Insbesondere setzen sie sich mit der Frage auseinander, welche Argumente überhaupt dafürsprechen, NOS im naturwissenschaftlichen Unterricht zu thematisieren. Aus der zum damaligen Zeitpunkt bereits vorhandenen Literatur leiten sie fünf Hauptargumente ab. Vier dieser Argumente zielen auf den intrinsischen Wert eines NOS-Verständnisses als Lernziel naturwissenschaftlichen Unterrichts, sei es für ein besseres Verständnis des Wissenschaftsbetriebs oder zur Bewertung wissenschaftlicher Standpunkte und Diskussionen (eine ausführliche Darstellung dieser Argumente findet sich in Abschnitt 1.1). Das fünfte Argument zielt jedoch auf einen extrinsischen Wert, den Driver et al. einem adäquaten NOS-Verständnis zusprechen. Nach dieser Argumentation soll NOS Lernenden dabei helfen, Fachwissen aus verschiedenen Disziplinen und Themenfeldern besser einordnen und miteinander verknüpfen zu können und somit das Lernen naturwissenschaftlicher Inhalte zu befördern („science learning argument“). Driver et al. diskutieren einzelne Studien, die entsprechende Zusammenhänge zwischen NOS und lernförderlichen Variablen untermauern, gehen aber nur in Teilen auf die möglichen Mechanismen hinter diesen Zusammenhängen ein. In der ersten dieser Dissertation zugehörigen Publikation wird daher eine ausführliche Betrachtung dieses Arguments vorgenommen, insbesondere unter dem Licht neuerer Forschungsergebnisse zu dem Thema. Dabei fällt auf, dass Driver et al. in ihrer Argumentation vor allem eher indirekte Mechanismen andeuten, bei denen sich ein adäquates NOS-Verständnis auf Variablen wie etwa Lernstrategien oder Motivation auswirkt, wel-

che wiederum in einem positiven Zusammenhang mit Fachlernen stehen. Solche indirekten Mechanismen, ihre theoretischen Grundlagen und die entsprechend vorhandene empirische Evidenz werden ausführlich in Abschnitt 3.3 betrachtet. Anschließend wird die Frage nach einem direkten Mechanismus diskutiert, bei welchem sich also ein Verständnis bestimmter NOS-Aspekte direkt auf das Lernen und den Verständnisszuwachs bzgl. bestimmter fachlicher Konzepte auswirkt (Abschnitt 3.4). In der Analyse zeigt sich, dass nach wie vor der Forschungsstand zu einem möglichen direkten Zusammenhang zwischen NOS-Verständnis und Konzeptverständnis gering ist und hier weiterer Forschungsbedarf besteht. Insbesondere epistemologische Aspekte naturwissenschaftlicher Konzepte wurden bisher zu wenig als mögliche wichtige Komponenten konzeptuellen Verständnisses untersucht und mit NOS-Aspekten in Verbindung gebracht (siehe Abschnitte 3.4 und 3.5, vgl. auch Papadouris & Constantinou 2011; 2014b; 2017). Abschließend werden die sich aus dieser Synopse ergebenden Implikationen für die naturwissenschafts-didaktische Forschung, wie auch für den naturwissenschaftlichen Unterricht dargestellt.

2.2 PUBLIKATION 2: NATURE OF SCIENCE AND SCIENCE CONTENT LEARNING: THE RELATION BETWEEN STUDENTS' NATURE OF SCIENCE UNDERSTANDING AND THEIR LEARNING ABOUT THE CONCEPT OF ENERGY

Ausgehend von den Ergebnissen der Synopse wurde in einer empirischen Studie der Zusammenhang zwischen NOS-Verständnis und der Entwicklung eines Verständnisses des Energiekonzepts während eines dreitägigen Ferienkurses mit Schülerinnen und Schülern der sechsten und siebten Jahrgangsstufe untersucht. Da NOS nicht explizit Bestandteil deutscher Bildungsstandards oder Kerncurricula ist (siehe Abschnitt 1.3), wurde bei den Schülerinnen und Schülern ein naives NOS-Verständnis vor Beginn der Unterrichtseinheit angenommen. Um zu untersuchen, wie sich ein adäquateres NOS-Verständnis auf Lernprozesse auswirkt, erhielt ein Teil der Stichprobe (41 Probanden) eine drei Doppelstunden umfassende Einheit zu NOS. Hierbei wurde besonderer Wert darauf gelegt, dass die NOS-Einheit keine Verknüpfungen zum Energiekonzept aufwies, ebenso wurden in der folgenden Einheit zu Energie (welche von allen 82 Probanden durchlaufen wurde) keine Rückbezüge zu NOS-Aspekten gemacht. Die Studie war entsprechend als quasi-experimentelle Studie mit Kontrollgruppendesign angelegt. Die Schülerinnen und Schü-

ler der Treatmentgruppe unterschieden sich jedoch nach Durchlaufen der dekontextualisierten NOS-Einheit in ihrem NOS-Verständnis im Durchschnitt nicht von den Schülerinnen und Schülern der Kontrollgruppe, die keine NOS-Einheit durchliefen. In Abschnitt 4.7 werden verschiedene mögliche Gründe für diesen Befund diskutiert, darunter das geringe Alter der Lernenden, die Kürze der NOS-Einheit und die möglicherweise unzureichende Passung zwischen den in der Einheit und im Messinstrument thematisierten NOS-Aspekten. Die Auswertung der Studienergebnisse erfolgte entsprechend nicht auf Gruppen-, sondern auf Individualebene durch Varianzanalyseverfahren. Die daraus resultierenden Limitationen werden ebenfalls in Abschnitt 4.7 diskutiert. Die Ergebnisse zeigen einen deutlichen Zusammenhang zwischen dem NOS-Verständnis der Lernenden vor der Einheit und ihrem Lernzuwachs bzgl. epistemologischer Aspekte des Energiekonzepts („nature of energy as a scientific concept“), auch wenn diese nur implizit in der Einheit thematisiert wurden.

2.3 PUBLIKATION 3: THEORETISCHE DENKMODELLE IM PHYSIKUNTERRICHT: EINE AN NATURE OF SCIENCE ORIENTIERTE HERANGEHENSWEISE AN DAS ENERGIEKONZEPT

Wie in Abschnitt 1.4 ausgeführt, sollte Unterricht über NOS bestenfalls kontextualisiert erfolgen, um einen authentischen Zugang zu dem teils recht abstrakten Themenfeld zu ermöglichen (Brickhouse et al., 2000; Clough, 2006; Driver et al., 1996; Schwartz & Crawford, 2006). Wie aus Publikation 1 hervorgeht, lässt sich auch für das Verständnis naturwissenschaftlicher Konzepte – insbesondere ihrer epistemologischen Aspekte – argumentieren, dass ein integrierter Ansatz, der NOS-Aspekte explizit mit fachlichen und epistemologischen Aspekten naturwissenschaftlicher Inhalte verknüpft, förderlich ist (siehe Abschnitt 3.4). Papadouris und Constantinou (2011; 2014a) konnten zeigen, dass ein entsprechender integrierter Unterrichtsansatz zum Energiekonzept sowohl das NOS-Verständnis als auch das Verständnis epistemologischer Aspekte des Konzepts fördern konnte. Aus der Perspektive von Lehrerinnen und Lehrern fehlt es für eine solche Implementierung von NOS allerdings vor allem an qualitativ hochwertigen Materialien für den Unterricht (Allchin, 2012). Konkrete Beispiele für eine Thematisierung von NOS in einem naturwissenschaftlichen Fachkontext sind begrenzt (Brickhouse et al., 2000; Hanuscin, Akerson & Phillipson-Mower, 2006; Khishfe & Lederman, 2006; Leach et al., 2003; Schwartz, 2013). In Publikation 3 wurden mehrere Beispiele für Aktivitäten, die NOS-Aspekte mit fachlichen

und epistemologischen Aspekten des Energiekonzepts verknüpfen, dargestellt und ihre Einsatzmöglichkeiten im Unterricht diskutiert. Die Aktivitäten richten sich in der skizzierten Form an Schülerinnen und Schüler der Jahrgangsstufen 6 und 7 und thematisieren fachlich vor allem die Aspekte der Energieumwandlung, -erhaltung und -entwertung. Auf der Seite epistemologischer Aspekte werden das abstrakte, theoretische Wesen, die disziplinübergreifende Natur, sowie die Erklärungsmächtigkeit und Vorhersagekraft des Energiekonzepts angesprochen. Die dort dargestellten Aktivitäten liefern gleichzeitig die Grundlage für den in der zweiten empirischen Studie entwickelten NOS-orientierten Unterrichtsansatz.

2.4 PUBLIKATION 4: NATURE OF SCIENCE AND SCIENCE CONTENT

LEARNING: THE IMPACT OF AN EPISTEMOLOGICALLY INFORMED UNIT ABOUT ENERGY

Nachdem in der ersten empirischen Studie (Publikation 2) der Zusammenhang zwischen NOS-Verständnis und Lernzuwachs bzgl. fachlicher und epistemologischer Aspekte während einer Unterrichtseinheit zum Energiekonzept untersucht wurde, lag der Fokus in der zweiten durchgeführten Studie auf dem Vergleich zweier verschiedener Unterrichtsansätze. Dabei wurde ein integrierter Ansatz, der NOS-Aspekte und fachliche Aspekte des Energiekonzepts miteinander verknüpft und dabei auch explizit auf epistemologische Aspekte des Konzepts eingeht, mit einem modernen, aber eher konventionellen Unterrichtsansatz verglichen, welcher weder NOS-Aspekte noch epistemologische Aspekte des Energiekonzepts explizit berührt. Nach den Erfahrungen mit der geringen gemessenen Wirksamkeit der NOS-Einheit in der ersten Studie und den in diesem Zusammenhang diskutierten möglichen Gründen dafür (siehe Abschnitt 4.7) wurde das Design der Studie entsprechend in einigen Punkten deutlich abgewandelt: Zum einen wurde mit Schülerinnen und Schülern der Oberstufe eine ältere Stichprobe gewählt, welcher ein Zugang zu dem abstrakten Thema NOS möglicherweise leichter fällt, zum anderen wurde zur Erhebung des NOS-Verständnisses ein anderes Instrument gewählt, welches genauer auf die in der Unterrichtseinheit angesprochenen NOS-Aspekte zielt um auch kleinere Veränderungen im Verständnis der Lernenden über die Dauer der Einheit messen zu können. Die möglicherweise problematische fehlende Kontextualisierung der NOS-Einheit in der ersten Studie entfiel zudem in diesem Fall durch die Konzeption der integrierten Einheit. Die beiden Unterrichtseinheiten wurden schließlich mit insgesamt 13 Oberstufenkursen

an Schulen in Schleswig-Holstein über einen Zeitraum von jeweils zwei Tagen durchgeführt. Insgesamt nahmen 191 Schülerinnen und Schüler an jeweils einem der Kurse teil. Auf der Ebene fachlichen Wissens über Energieformen, -transfer, -umwandlung und -entwertung zeigten Lernende in beiden Gruppen vergleichbare signifikante Lernzuwächse. Bzgl. NOS-Verständnis und einem Verständnis der epistemologischen Aspekte des Energiekonzepts zeigten Schülerinnen und Schüler, die an der integrierten Einheit teilgenommen hatten, deutlich höhere Verständnisgewinne als die Teilnehmenden der konventionellen Unterrichtseinheit. Weitere Ergebnisse, sowie Implikationen für Forschung und Unterricht werden in Publikation 4 diskutiert.

3 PUBLIKATION 1: HOW DOES NOS UNDERSTANDING CONNECT TO CONCEPTUAL UNDERSTANDING? THEORETICAL CONSIDERATIONS

Michel, H., Papadouris, N., Neumann, I., Charalambous, M., & Constantinou, C. P. (under review). How does NOS understanding connect to conceptual understanding? Theoretical considerations.

Abstract: Ever since nature of science has become a focus of science education research, multiple scholars have postulated potential connections between NOS understanding and science learning. As early as 20 years ago, for instance, Driver, Leach, Millar, and Scott (1996), suggested that NOS understanding may foster the acquisition of conceptual understanding of science content. However, this connection has been conceptualized in many different ways. Sometimes, NOS is said to foster students' motivation or cognitive factors, thus indirectly improving science learning in the long term. Sometimes, NOS understanding is suggested to directly impact how students build or integrate knowledge about a certain science concept. Both direct and indirect connections between NOS understanding and conceptual understanding in science (that are sufficiently substantiated by empirical evidence) impact the way in which NOS would have to be further addressed in science teaching, as well as in science education research. In this article, we aim to provide a synopsis of how these connections have been theorized, and to what extent they have been investigated empirically. Building on our synopsis, we point out epistemic and ontological aspects of scientific concepts as integral parts of students' conceptual understanding and elaborate, how such aspects might benefit from NOS understanding. We finally discuss potential avenues for further research, as well as implications for science teaching.

Keywords: *nature of science; conceptual understanding; epistemological beliefs*

3.1 INTRODUCTION

Within the last three decades, nature of science (NOS) has become increasingly acknowledged as a critical component of scientific literacy (Lederman, 2007), and has subsequently been implemented in various science education reform documents worldwide (McComas & Olson, 1998; Millar & Osborne, 1998; NGSS Lead States, 2013). NOS, in this sense, 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 a broad support among scholars for including such aspects in science teaching and learning (and thus in science education research as well), there is an ongoing debate on how to conceptualize NOS as a component of science education, and to what extent it should incorporate aspects of, for example, history of science, scientific inquiry, or socio-scientific issues (see e.g. Hodson & Wong, 2017). Several efforts have been made to provide a set of aspects that can guide and inform science teaching (e.g. Lederman, 2007; McComas & Olson, 1998; Osborne et al., 2003), with the conceptualization of Lederman (sometimes called the “consensus view”) being used quite often in empirical science education research. Recently, some scholars have criticized the “consensus view” and have proposed alternative approaches towards conceptualizing NOS (e.g. Allchin, 2017; Dagher & Erduran, 2017; Hodson & Wong, 2017). However, assessment instruments explicitly aligning to these alternative approaches (and thus empirical studies drawing on such instruments) are scarce (Allchin, 2017).

Although there are different approaches on conceptualizing and teaching NOS, all of the mentioned approaches share common aspects or features that they advocate to be important for NOS understanding, such as the tentative nature and socio-cultural embeddedness of scientific knowledge. Furthermore, they draw on similar arguments for including NOS in science teaching and learning.

ARGUMENTS FOR INCLUDING NOS AS A GOAL OF SCIENCE EDUCATION

Understanding NOS has been widely acknowledged as a significant learning outcome of science teaching. Also, it has been portrayed as a vehicle for promoting additional aspects of conceptual understanding. Driver, Leach, Millar, and Scott (1996) have provided an

elaborate rationale underlying the importance of NOS, as early as 20 years ago. In particular, NOS is supposed to help people in making sense of science and technological objects in everyday life (utilitarian argument), as well as to empower them to engage in decision-making processes related to science (democratic argument). Furthermore, it is considered likely to lead to increased appreciation of science as an element of contemporary culture (cultural argument) and awareness of the norms and moral commitments shared within the scientific community (moral argument). These four arguments refer to the inherent value of NOS as an important instructional outcome. Finally, the fifth argument, which is the focus of the present article, rests on the connection between NOS and science learning per se. In particular, it is predicated on the assumption that an emerging NOS understanding is likely to support the acquisition of disciplinary content knowledge (science learning argument).

In line with the latter argument, we believe that embarking on the task of articulating the connection between NOS and facility with disciplinary content knowledge, to which we hereafter refer to as conceptual understanding, constitutes a worthwhile research topic that could yield valuable insights. For example, if NOS understanding indeed provides a mechanism for promoting conceptual understanding, curriculum developers should integrate NOS in the design of curriculum materials for content topics such as energy, evolution or magnetism.

PURPOSE OF THIS ARTICLE

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). In this contribution, we therefore seek to provide a synopsis articulating what is already known about the connection between NOS and conceptual understanding, and to derive subsequent implications for teaching, learning, and further research. To this end, we take the original science learning argument by Driver and colleagues (1996) as a point of departure. We identify two possible trajectories of how NOS may be connected to conceptual understanding, which are shown in figure 1. The first connection draws on *indirect mechanisms* connecting NOS and conceptual understanding. That is, NOS understanding could come to enhance conceptual understanding by means of other mediating variables. Such mediating variables include, for example, self-beliefs, motivation, learning strategies or metacognition. All these variables are known to impact learning in

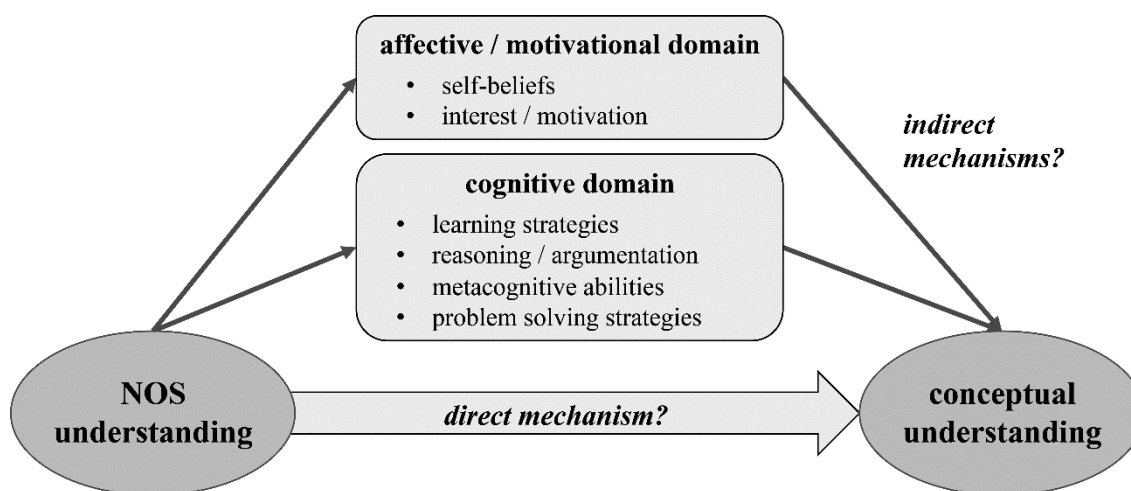


Figure 1: Overview of the investigated mechanisms for the potential connection between NOS understanding and conceptual understanding

general, not just science learning in particular. The second trajectory, on the other hand, envisions a *direct mechanism* by means of which improvements in students' understanding of NOS directly induce improvements in conceptual understanding regarding science content.

Given the two possible mechanisms, our synopsis is guided by the following research questions: First, what are the main indirect mechanisms connecting NOS and conceptual understanding that are reported in the extant research literature and to what extent are they theoretically and empirically substantiated? Second, to what extent are potential direct mechanisms supported by the available literature and under what perspective have they been investigated to date? And finally, what implications can be derived from the evidence at hand, regarding the role of NOS understanding in science teaching and learning, as well as further science education research?

3.2 THE SCIENCE LEARNING ARGUMENT FOR IMPLEMENTING NOS IN SCIENCE TEACHING

According to Driver et al. (1996) 'an understanding of the nature of science supports successful learning of science content'. This science learning argument has been rather pervasive in the extant research literature. McComas, Almazroa, and Clough (1998), for instance, call on this argument in their attempt to explicate the value of NOS for teaching and learning. In his comprehensive review of NOS research, Lederman refers to the potential connection between NOS and conceptual understanding when he puts forward the

question whether ‘knowledge of the nature of science improve[s] students’ learning of other science subject matter’ (Lederman, 2007, p. 871). Similarly, Deng, Chen, and Tsai (2011) draw on the given argument when motivating their literature review on research regarding students’ views of NOS and how they develop.

Before the science learning argument was formulated by Driver and colleagues, Songer and Linn already assumed that “students’ beliefs about science might empower them to participate in science courses and to integrate science knowledge” (Songer & Linn, 1991, p. 766). Accordingly, Driver et al. include this study in their rationale for a connection between nature of science and science learning as the study was “investigating the relationship between student epistemologies of science and conceptual learning” (Driver et al., 1996, p. 21). It is clear from these quotes that conceptualizations of NOS, or related concepts, as well as the way in which they are assessed varied greatly throughout the research literature – and are still varying. Songer and Linn (1991), for example, use the notions ‘views of science’, ‘beliefs about science’ and ‘beliefs about the nature of science’ throughout their article in a somewhat interchangeable manner. Furthermore, they describe their evaluation instrument as assessing “students’ beliefs about the nature of science and scientific knowledge, beliefs about the role or work of scientists, and beliefs about what it means to learn science” (Songer & Linn, 1991, p. 769) – a conceptualization which appears close to that of the concept of epistemological beliefs, which is broadly used in the field of educational psychology (see e.g. Schommer, 1993). While the conceptualizations of NOS or other epistemology-based constructs differ, it thus seems important to take into account findings and rationales from all different fields when investigating the effects of such factors on students’ learning.

Originally, Driver and colleagues built the assumption that NOS understanding might foster the acquisition of conceptual understanding on theoretical considerations, as well as on evidence from empirical science education research. They argued that if students see scientific knowledge as an accumulation of facts (which would resemble a naive understanding of NOS), they would be more likely to adopt rote learning strategies, rather than more elaborate ones. Also, students often regard scientific knowledge as something largely incomprehensible to most people and only accessible to a restricted group of privileged people (Driver et al., 1996). If they do not understand that scientific theories and explanations do not just ‘emerge’ from observational data, but that they evolve over time

and that their construction involves creativity – thus making science a human enterprise that everybody can participate in – this may lead to a lack in motivation which would eventually result in slower learning of science content. Based on the literature (Driver & Oldham, 1986; Millar, 1987; Solomon, 1991), Driver and colleagues reasoned that such ideas about scientific knowledge may be taught by not only ‘doing’ laboratory work, but also by reflecting on it. Moreover, referring to Hodson (1988), Solomon (1991), and Duschl (1990), they proposed that drawing analogies between the historical progress of scientific understanding and students’ own experiences while acquiring conceptual understanding may assist them in understanding the tentative nature of scientific knowledge, as well as their own conceptual learning. Driver and colleagues then emphasized the importance for students to understand the nature of scientific theories, as well as the criteria which are used to judge these theories (e.g. parsimony, consistency, explanatory power). Being able to use these criteria to distinguish between legitimate and inept theories, and to understand why due to violations of these criteria (e.g. due to new observations) theories can change over time, would foster their ability to develop a proper understanding of science content. Overall, these considerations represent a rather indirect impact of NOS understanding on students’ science content learning, mediated by factors such as students’ motivation, learning strategies, or beliefs about learning. Matthews (1997), in contrast, presented a rationale which implicates a more direct connection between NOS understanding and students’ learning, at least concerning epistemological issues of science in general and certain science topics in particular. According to his argumentation, for instance, the controversy about evolution/creationism is strongly connected to an understanding of the nature of science. Likewise, he states that important epistemological issues of modern science education, like conveying a multicultural or gender-diverse view on science, rely on a perception of NOS (see also McComas et al., 1998). Papadouris and Constantinou (2017) argue, that not only epistemological issues of science in general, but also epistemological aspects of certain science concepts in particular should be better recognized in science instruction, as they are important for understanding the inherent values and purposes of scientific concepts, thus forming a constitutive part of conceptual understanding (see also Bächtold & Guedj, 2014).

Despite the widespread and long-standing assumption that NOS may serve to promote conceptual understanding, there still seems to be little agreement about the potential role and the exact mechanisms. The present article aims at contributing to this open question from a theoretical point of view, re-evaluating and expanding the science learning argument and its rationale in the light of theoretical and empirical works of the last two decades. In our synopsis, we draw on studies and rationales that use different conceptualizations or definitions of NOS (or related constructs), but share a common aspects. These aspects include, among others, an understanding of the tentativeness of scientific knowledge, its empirical base, the role of subjectivity and creativity in science, and the meaning of different scientific terms. Driver and colleagues (1996) dedicated a whole chapter to ‘perspectives on the nature of science’, conveying that there may legitimately be different positions regarding NOS, as an agreed ‘expert’ understanding of the concept is not well-defined. As the current debate shows, this is still true today (see e.g. Hodson & Wong, 2017). Furthermore, the science education, as well as the educational psychology literature, contains several other epistemology-based concepts (e.g. ‘epistemological beliefs’, ‘scientific epistemological beliefs’, ‘science-related epistemological beliefs’, ‘ideas about science’ etc.). These concepts show great overlap with the aforementioned aspects of NOS (Hogan, 2000; Khishfe, 2012b) – all of them, for instance, cover the aspects of certainty and justification of scientific knowledge. NOS understanding and science-related epistemological beliefs, for example, can be regarded as not being identical, but very closely related (Neumann & Kremer, 2013). Thus, while many studies are using other terms than ‘NOS understanding’ when drawing relationships between epistemology and conceptual understanding (or factors that could mediate this relationship), we decided to include them in our literature review, subsuming these concepts under the term ‘nature of science’, in the tradition of Driver et al. (1996). We think that excluding works, which do not explicitly frame themselves as NOS-related, but share a similar framework, could result in ignoring important contributions to the issue. We took care that all study results that we incorporated would refer to aspects that are generally argued to be a part of NOS understanding as described above, even when in the context of the respective study they are put under a different overarching concept.

3.3 METHODOLOGY AND LIMITATIONS

In the following sections, we first investigate the empirical evidence reported in the extant research literature for possible indirect mechanisms that mediate between NOS and conceptual understanding. In doing so, we use Driver and colleagues' argument and the potential mechanisms provided in the underlying rationale as a starting point, but also elaborate on some additional mechanisms we were able to identify. Subsequently, we elaborate on a potential direct mechanism in which NOS understanding might facilitate conceptual understanding.

Regarding studies on indirect mechanisms, in which NOS (or epistemological) understanding is not directly linked to conceptual understanding but to other learning-related variables, a literature search in relevant databases revealed more than 50 articles referring to such studies, and a lot more which link these learning-related variables to learning achievement and conceptual understanding. While it might be valuable to undertake a systematic literature review or even a meta-analysis to compare the different effects, it would be difficult to derive reliable results, as hardly any of the studies take into account both sides of an indirect mechanism – the relation between NOS understanding and the investigated learning-related variable on the one hand, and between this variable and conceptual understanding on the other hand. Conclusions on indirect mechanisms thus have to be drawn by including different studies for each mechanism, often using slightly different conceptualizations (and assessment instruments) for the underlying variables and thus accounting for some uncertainty. Furthermore, learning-related affective and cognitive variables are considered to affect students conceptual understanding rather in the long term (e.g. Krapp, 2005; Vollmeyer, 2007), making it even more difficult to reliably investigate their effect. Given these considerations, we decided to rather collate the main indirect mechanisms we were able to identify, drawing on about 30 studies that represent these main mechanisms, instead of developing an exhaustive review. At the same time, it should be noted that most of these studies investigate correlations rather than employing experimental designs, so that causal relations (i.e. purely one-directional mechanisms) cannot generally be substantiated. For instance, instead of inferring that NOS understanding influences students' learning strategies it could also be reasoned that the structure of academic tasks and how students approach them might influence NOS understanding, as Hofer and Pintrich (1997) point out. Hacieminoglu, Ertepinar, Yilmaz-Tüzün, and Cakir

(2014) used hierarchical modelling to investigate student factors that might influence NOS understanding, instead of the other way around, finding relations to learning approaches, self-efficacy, and motivational goals. However, as we aim to investigate Driver and colleagues' (1996) science learning argument, which is formulated as being one-directional, and as almost all of the articles we found (empirical and theoretical) theorize one-directional relations how NOS understanding might influence learning-related factors, we focus on explicating this direction of the mechanism.

Compared to the vast research base on indirect mechanisms, there are only few research studies that bear a connection to a direct mechanism. Thus, we employed a more systematic approach for this part of our synopsis. To ensure an inclusive approach, reducing the probability of omitting relevant studies, we systematically searched the available research literature by querying the Scopus database using appropriate keywords. The inclusion criteria that we relied on are as follows: the research publications should involve (a) a classroom intervention focusing on the two variables of interest (i.e., understanding of NOS and conceptual understanding), (b) collection of assessment data about students' learning gains with respect to these two variables, as a result of the teaching intervention, (c) an experimental pre/post-test design (focusing on the two variables) with a comparison and an intervention group. This led us to identify a set of 21 potentially relevant publications. The selection process then proceeded to a second stage which introduced an additional criterion. This pertained to the employment of a methodological design that could (potentially) support claims about the presence (or lack) of a direct mechanism between the two variables of interest. This criterion was intended to ensure that the selected publications could indeed illuminate our attempt to evaluate the empirical grounding of the direct connection between NOS understanding and conceptual understanding. In particular, studies lacking this methodological design could not bring about relevant evidence about the issue at hand since the seeming connection between conceptual understanding and NOS understanding that manifested in the data could be accounted for as a mere covariation, mediated by a third variable. For instance, the indirect mechanisms elaborated in the previous section could be held responsible for this covariation. The application of this additional criterion reduced the set of potentially articles to eight. However, the fact that the remaining 13 studies did not satisfy this criterion should certainly not be interpreted as a judgment of the rigor or quality of the research articles. It could be simply because the specific studies may have not explicitly probed the relevant connection.

3.4 INDIRECT MECHANISMS FOR A CONNECTION BETWEEN NOS AND CONCEPTUAL UNDERSTANDING

Research on how NOS understanding connects to learning-related variables on the one hand, and how such variables connect to actual conceptual understanding on the other, has been rather prominent in the research literature on science education and the learning sciences. The main mechanisms researched in the literature can be clustered into two major categories: (1) influences mediated by affective and motivational variables, and (2) influences mediated by cognitive variables.

INFLUENCE OF NOS UNDERSTANDING ON AFFECTIVE AND MOTIVATIONAL VARIABLES

The literature provides a broad picture on how NOS understanding influences a variety of affective and motivational variables, which sometimes overlap or are summarized under more general terms from educational psychology. In the following, we will mainly differentiate between self-beliefs on the one hand, and interest and motivation on the other.

Self-beliefs

One mechanism discussed in the literature builds on the idea that the way students see the status of scientific knowledge and the nature of the underlying processes is related to their views of their own abilities and competence in a certain domain, i.e. their self-beliefs (the term self-beliefs is intended to subsume both self-concept as well as self-efficacy). It is commonly reasoned that students' self-beliefs have effects on cognitive (e.g. task orientation in case of setbacks) as well as motivational (e.g. effective goal-setting), or affective (e.g. anxiety arousal) processes (Bandura, 1994). Several studies provide evidence that self-beliefs influence students' interest, motivation and, eventually, their learning achievement (Fadlelmula, Cakiroglu & Sungur, 2015; Leibham, Alexander & Johnson, 2013; Niemivirta & Tapola, 2007; Steinmayr & Spinath, 2007; Vollmeyer, 2007).

As for the connection between NOS understanding and self-beliefs, several mechanisms have been theorised. Students often regard scientific knowledge as 'true' and un-doubtful (Höttecke, 2001b; McComas, 1996) and view scientists as highly intelligent but unsocial individuals who work alone on complicated experiments, where they 'discover' laws and theories that are incomprehensible for the 'average' person (Driver et al., 1996; Höttecke, 2004). Such understanding of science presumably bears the risk of leading students to

think that they themselves are not made for science (Driver et al., 1996; Höttecke, 2001a). Understanding that science is a highly social endeavour and that scientific knowledge is always subject to revision and change – important aspects of NOS – could help to raise students' self-beliefs and to counter the risk of viewing science as something exclusive. By reconstructing historical research processes, and thus reflecting on NOS aspects such as tentativeness, subjectivity, and the role of creativity in science, students could realise that their own questions and problems have occasionally been the same in the history of science, a notion potentially fostering their self-beliefs (Höttecke, 2001a).

The connection between NOS understanding and self-beliefs has been substantiated by several empirical studies. Urhahne and Hopf (2004), for example, found a positive influence of a sophisticated NOS understanding on students' self-concept in physics and biology. Results of the German part of the Third International Mathematics and Science Study (TIMSS/III), which investigated more than 5000 upper secondary students' mathematics and science literacy, indicated a similar relationship concerning NOS understanding and self-concept (Baumert, Bos & Lehmann, 2000). The authors of that study concluded that NOS understanding is an important element of intelligent learning in school, which is insufficiently appreciated to date. Hofer (1994) found that, for university students, a sophisticated understanding of several NOS aspects correlated with students' self-efficacy; a finding, which was further substantiated by Tsai, Ho, Liang, and Lin (2011), who found that in a study with high school students, sophisticated NOS understanding was related to higher-level conceptions of learning science and higher self-efficacy as well. However, students with more sophisticated beliefs about the uncertainty of scientific knowledge tended to possess lower self-efficacy. In a study with more than 3.500 seventh grade students, Hacıeminoğlu (2016) found students' NOS understanding to be related to their self-efficacy, their attitudes towards science, as well as to other learning related factors. Focusing on the role of NOS instruction (rather than NOS understanding), Parker (2010) found that addressing NOS during science instruction successfully improved students' self-efficacy beliefs.

Regarding the aforementioned literature, the indirect relation between NOS understanding, self-beliefs, and science content learning can legitimately be viewed as well-established – however, the negative correlation between beliefs about uncertainty and self-

efficacy beliefs, as identified by Tsai et al. (2011), should be investigated in more detail, so as to identify how this relation can be addressed instructionally.

Interest and motivation

Both interest and motivation have been shown to be important prerequisites for students' engagement in learning processes and thus strong contributors to later student achievement (Boekaerts, 2007; Cavallo, Rozman, Blickenstaff & Walker, 2003; Chi, Wang, Liu & Zhu, 2017; Deci & Ryan, 1985; Lee, Hayes, Seitz, DiStefano & O'Connor, 2016; Leibham et al., 2013; Vollmeyer, 2007). Several scholars have theorized that a higher transparency regarding the genesis and the characteristics of scientific knowledge could help keeping up students' interest in science, as well as their motivation (Clough, 2011; Driver et al., 1996; McComas et al., 1998). For their science learning argument, Driver and colleagues drew on the findings, for instance, of Kuhn, Amsel, and O'Loughlin (1988) and Carey, Evans, Honda, Jay, and Unger (1989) to elaborate on how students' knowledge about the relationship between observations, evidence, explanations, and theories may influence their ability to meaningfully interpret evidence and to make sense of scientific explanations, thus being more motivated to engage in science. Developing sophisticated ideas about the importance of creativity, e.g. by reflecting on historical case studies, and showing that not only machine-like geniuses did and do science, but people who dedicate their interests, time and efforts to it, might raise students' own willingness to dedicate their time to engaging in science. Similarly, appreciating science as a social and societal process (an important NOS aspect) that includes working with people and for the benefit of others is thought to help in raising students' interest in science (Clough, 2011). In that way, students can appreciate science as a human endeavour, instead of a pure accumulation of facts (McComas et al., 1998). Finally, being aware of some of the many questions that are still open in science and thus realizing that scientific knowledge is still tentative and evolving – and something that they themselves could contribute to – provides tempting incentives for students to become engaged in science. Henderson, McPherson, Osborne, and Wild (2015) argue that engaging students in critique about scientific ideas, thus making them aware of the tentative and subjective nature of scientific knowledge, should be emphasized much more in science education, as it would (among other factors) improve students' motivation to engage in scientific discussions.

Again, empirical data from research on NOS understanding corroborates these assumptions. Hofer (1994) and Tsai (1998), for example, found that for university students, sophisticated NOS understanding correlated with students' intrinsic motivation. This finding was further substantiated by Lin, Deng, Chai, and Tsai (2013), who found that beliefs about the development and justification of knowledge as well as about the creativity of scientists relate to deep motives for learning science. Buehl and Alexander (2001) found that sophisticated NOS understanding correlated to students' motivation; a finding, which is also substantiated by the results of Alpaslan, Yalvac, Loving, and Willson (2016). Based on the TIMSS/III data, Baumert et al. (2000) established an indirect influence of NOS understanding on conceptual understanding, mediated by interest. Kruse (2010) showed that NOS instruction positively influences students' interest in science and in scientific professions. Studies investigating the role of particular components of NOS understanding, however, revealed rather ambiguous results. For example, Urhahne and Hopf (2004) on the one hand found that students with sophisticated beliefs about the role of experiments and the development of knowledge had higher interest and motivation, but they also found students with less sophisticated beliefs about the role of authority in science and about the certainty of scientific knowledge to have higher interest in science as well. Similarly, Ho and Liang (2015) found sophisticated NOS understanding to be correlated with constructive conceptions of learning science, which in turn correlated with deeper motives for learning science, but sophisticated beliefs regarding the uncertainty of scientific knowledge correlated positively with surface motives for learning science. Ho and Liang reasoned that this contradiction may stem from the regional context of the study (Taiwan), but it implies the necessity of further investigation.

Altogether, affective and motivational variables such as self-beliefs, interest, and motivation have been shown to contribute to students' science content learning and seem to be influenced by students' NOS understanding. From a general perspective, the relations between these constructs are well-established and well-supported by empirical data. However, motivational or affective factors are thought to affect learning rather in the long term (e.g. Krapp, 2005; Vollmeyer, 2007); this makes these indirect mechanisms difficult to observe directly during science instruction.

INFLUENCE OF NOS UNDERSTANDING ON (META)COGNITIVE ABILITIES AND VARIABLES

Several cognitive abilities and variables have been shown (or are hypothesized) to have an effect on learning achievement (e.g. Cavallo et al., 2003). For their science learning argument, Driver and colleagues referred to studies, for example, by Shapiro (1988) and Songer and Linn (1991), which provided evidence that metacognitive knowledge can support conceptual learning in science. Scholars have theorized different reasons as to how NOS understanding might influence students' learning-related cognitive and metacognitive skills. For learning strategies, for example, science educators argue that students' who believe that scientific knowledge is a collection of facts might be more likely to use rote-learning strategies, whereas those believing that scientific knowledge is something that develops over time, tend to prefer more integrated learning approaches (Hofer & Pintrich, 1997; Tsai, 1998). Sophisticated NOS understanding is also thought to influence the claims students make during argumentation, as well as the factors they use for decision-making (Khishfe, 2012a). For both skills, a constructivist² understanding of NOS might lead to a more balanced view of conflicting evidence, compared to thinking that scientific claims be either right or wrong (Khishfe, 2012a; 2012b). Henderson and colleagues (2015) argue that using critique to engage students in discussions about NOS aspects such as tentativeness and subjectivity would also foster their reasoning skills and their ability to formulate constructive questions. Finally, Bromme, Pieschl, and Stahl (2010) reasoned, that NOS understanding may serve as a lens for learners' views on what is to be learnt, thus fostering metacognitive abilities such as goal-setting.

Theoretical arguments like the above are also supported through empirical evidence. Comparing students' NOS understanding and their learning strategies, Tsai (1998) found, that more sophisticated beliefs correlated with more constructivist learning strategies for learning science. Similarly, Urhahne and Hopf (2004) found that stronger beliefs in the development of knowledge and an appropriate appreciation of the role of experiments for scientific knowledge acquisition are positively related to cognitively elaborated learning strategies. Interestingly, they also find this effect for students with stronger beliefs in authorities as facilitators of scientific knowledge, which, according to Urhahne and Hopf, could be explained by the age level of the students (age 15-16), at which they are generally more critical towards authorities, making the results somewhat difficult to interpret.

² that is, that scientific knowledge is constructed through discourse among scholars

Alpaslan, et al. (2016) found students' NOS understanding to be related to their rehearsal and organization strategies, as well as to their metacognitive self-regulation. Lee, Liang, and Tsai (2016) chose to investigate the nature of this mechanism in more depth and found a positive relation between students' beliefs regarding uncertainty and justification in science and their learning strategies in biology, mediated by their learning conceptions.

In an intervention study, Bell and Linn (2000) found that students' NOS understanding was correlated with several of their argumentation characteristics. Students, who viewed science as dynamic, tended to be able to construct more powerful arguments. Archila (2015) implemented NOS ideas into a historical context to engage students in argumentative classroom interactions and reasoned that such learning environment can promote students' argumentation skills as well as their NOS views. Khishfe (2012a, 2012b, 2014) showed that students' argumentation skills (such as construction of strong counterarguments) relate to a more informed NOS understanding, and that including NOS aspects in instruction about argumentation influences students' decision-making factors, i.e. the type of arguments they utilize to make their claim. Bell and Lederman (2003), however, did not find such influence of students' NOS understanding on their decision making. Assessing university students' NOS understanding in comparison to the decisions they made regarding issues of science-technology-society, the factors influencing their decisions, and their decision-making strategies, they found that these were strongly influenced by personal values, morals/ethics, and social concerns in general, but not by their NOS understanding in particular. Khishfe (2012a), on the other hand, found that students engaging in a teaching sequence about a socio-scientific issue differed in their decision-making factors, depending on whether NOS aspects were included in the teaching sequence. For goal-setting, an assessment study with university students, conducted by Cavallo et al. (2003), showed a tentative view of science to be positively related to students' learning goals in biology, which predicted their overall course achievement, but the authors could not find this relation for physics. Similarly, Hacıeminoğlu (2016) found a relation between students' NOS understanding and their learning goal orientation. Focusing on the effect of NOS instruction – as opposed to NOS understanding – Engelmann, Neuhaus, and Fischer (2016) conducted a meta-analysis in which they found a positive effect of NOS-oriented instruction on students' scientific reasoning skills.

Similar relations between NOS understanding and cognitive abilities or variables have been found for students' knowledge integration (Songer & Linn, 1991), problem solving strategies (Lin & Chiu, 2004), and inquiry skills (Kremer, Specht, Urhahne & Mayer, 2014). Also, Ferguson and Bråten (2013) found, that strong beliefs in the justification of scientific knowledge by multiple sources, in combination with high content knowledge, related to students' performance in multiple-text comprehension.

For some of the named cognitive variables, the connection between NOS understanding, cognitive variables, and science content learning can be regarded as well-established. However, due to the broad variety of different concepts in the cognitive domain and the sometimes-difficult delineation of one from the other, the picture on the indirect mechanisms remains somewhat unclear. Further investigation could therefore help to clarify the effects – both size and durability – of the different mechanisms and the potential interactions between them.

3.5 DIRECT MECHANISMS FOR A CONNECTION BETWEEN NOS AND CONCEPTUAL UNDERSTANDING

In this section we focus on what the available research seems to be suggesting for the existence of a direct connection between improved NOS understanding and growth in conceptual understanding. As stated in the methodology section, our review of the literature was restricted to eight research articles that met the specified inclusion criteria (see Table 1).

INSIGHTS FROM EMPIRICAL RESEARCH ON A DIRECT MECHANISM

The eight studies that we identified differ in their sample sizes and age group, as well as in the domains of science conceptual understanding that they focused upon (see Table 1). Peters' study (2012) involved a large sample (N=246) of eighth graders and was situated in the content domain of electricity and magnetism. The experimental group was exposed to explicit teaching about certain aspects of NOS (e.g., the empirical nature of scientific knowledge, distinction between laws and theories, role of creativity in science) whereas the control group did not receive any explicit teaching about these aspects. This study reported statistically significant differences between the post-instruction performance of the students in the two groups on both, understanding of NOS and content knowledge

about electricity and magnetism. Also, Lin, Chan, and van Aalst (2014), report on a study with 102 5th graders intended to compare the possible effect of engagement with an epistemologically-informed teaching approach on the learning outcomes in terms of epistemic and conceptual understanding. Their findings indicate a positive effect and suggest that increased epistemic awareness seems to contribute to conceptual understanding. A recent study by Michel and Neumann (2017) investigated the effect of an explicit NOS unit on students learning gain in a subsequent unit on energy. The data suggested that students with a higher NOS score in the pre-test showed a significantly higher learning gain during an energy unit focusing mainly on energy degradation, while this was not the case for a unit about energy forms, transfer, and conservation.

On the other hand, the studies by Kim and Irving (2010), Schwarz and White (2005), Irwin (2000) and Seker & Welsh (2006) led to different results. Kim and Irving (2010) focused on 33 tenth graders and explored whether their understanding of genetic concepts and NOS improved after the implementation of a specially designed curriculum. Their data failed to detect a significant impact of NOS improvement on the development of conceptual understanding. Schwarz and White (2005) investigated whether students' development of understanding about the nature of models could have an impact on their understanding about force and motion. Participants in this study were seventh graders and data analysis failed to detect a statistically significant difference between the gain scores in participants' content knowledge in the experimental and the control group, which implies a lack of a potential NOS impact. Irwin (2000) reports on a study with 42 ninth graders investigating whether situating the elaboration of content knowledge (atomic theory) in its historical context could produce a favorable effect with respect to conceptual understanding. The data did not show such an effect. Seker and Welsh's (2006) study explored this same topic (potential of framing teaching of content knowledge in its historical context to facilitate learning) in the case of a classroom intervention with 91 eighth graders in the topic of force and motion. The empirical data did not indicate significant differential effect of this teaching approach on the improvement of conceptual understanding. Klopfer & Cooley (1963) sought to address the role of teaching about history of science on conceptual understanding but focused on a broader range of domains drawn from biology, chemistry and physics (N = 108 high school students). The data suggested a lack of any effect on conceptual growth in physics and chemistry but indicated a negative effect in the case of biology.

Table 1: Selected empirical publications reporting on the direct mechanism between NOS and conceptual understanding.

Author/ Journal	Content domain	Targeted aspects of NOS	Sample	Evidence for the connection (or lack thereof) between NOS and conceptual understanding
Peters (2012) <i>Science & Education</i>	Electricity and magnetism (e.g. - permanent magnets, electromagnets, static electricity, electric current)	<ul style="list-style-type: none"> - Empirical evidence is used to support ideas in science - Laws and theories serve a different function as elements of the structure of scientific knowledge. - Creativity in science - The social aspect of scientific inquiry might facilitate progress in science (e.g. peer review could help to refine scientific ideas). 	246 8 th graders	<p>Strong positive correlation $r(246) = 0.71, p < .001$ between the content measure and the nature of science measure</p> <p>The explicit group had a greater gain both in content knowledge and NOS knowledge.</p>
Lin, Chan & van Aalst (2014) <i>Paper pres. at the 11th international conference of the Learning Sciences</i>	Electricity (e.g. conductivity of different materials)	<ul style="list-style-type: none"> - Theory building and theory revision - Theory-fact understanding - Social process of scientific inquiry 	102 5 th graders	Experimental group exhibited higher gains on epistemic views of science and on conceptual understanding. Also, regression analysis indicated that epistemic cognition contributed to students' conceptual understanding.
Michel & Neumann (2017) <i>Science & Education</i>	Energy (e.g. energy forms, transformation, conservation and degradation; explanatory power of energy)	<ul style="list-style-type: none"> - Difference between observation and inference - Nature of scientific theories - Subjectivity in science 	82 6 th and 7 th graders	<p>Students with higher NOS scores in the pretest showed higher learning gains regarding epistemological aspects of energy ($p < .05$)</p> <p>Students with higher NOS scores in the pretest achieved higher learning gains with respect to the property of energy degradation ($p < .05$)</p>
Kim & Irving (2010) <i>Science & Education</i>	Genetics (e.g. gene, DNA, allele, chromosome, heredity, cell, meiosis, phenotype, genotype, trait)	<ul style="list-style-type: none"> - Empirical nature of science - Tentative nature of science - Social and cultural nature of science - Creativity and imagination in science - Distinction between theory and law 	33 10 th graders	Students in the experimental group achieved a similar level of understanding regarding genetics concepts after the invention as students from the control group ($p > 0.05$)

Author/ Journal	Content domain	Targeted aspects of NOS	Sample	Evidence for the connection (or lack thereof) between NOS and conceptual understanding
Schwarz & White (2005) <i>Cognition and Instruc- tion</i>	Force and motion	- Nature of models	7 th graders	Positive correlation (physics posttest score - modelling pre- test $r = 0.47$, physics posttest - modelling posttest $r = 0.47$); no statistical difference be- tween gain scores with regards to physics knowledge between the two groups, $t(128) = 0.16, p=0.87$
Irwin (2000) <i>Science Education</i>	Atomic theory	- Empirical nature of science - Role of creativity - Social embeddedness of scientific knowledge	42 9 th graders	There was no difference in un- derstanding of science content between the two groups.
Seker & Welsh (2006) <i>Science & Education</i>	Motion and force	- Scientific method - Inference - Tentativeness - Subjectivity	91 8 th graders	The changes between classes in the meaningful learning scores for either the motion or the force unit did not show sig- nificant differences.
Klopfer & Cooley (1963) <i>Journal of Research in Science Teaching</i>	Biology, Chemistry, Physics	- Scientific enterprise - Scientists - The methods and aims of science	2808 high school students	Biology: students in the con- trol group show more achieve- ment in the usual content of the biology course, than stu- dents in the experimental group. Chemistry and Physics: stu- dents who study under the HOSC instruction method show the same achievement in the usual content of the chem- istry and physics course, as students who do not.

It is important to bear in mind that only one of these studies (Michel & Neumann, 2017) was explicitly designed to explore the direct connection between NOS and conceptual understanding. The other seven mainly targeted other relevant research questions but were included in our literature review because they met the inclusion criteria we drew upon. This decision to include these studies could account, at least partly, for the conflicting results reported by the studies. Indeed, the difference between the control and the experimental group in these studies was not strictly restricted to the presence of explicit teaching about NOS. For instance, in Peters' (2012), Schwarz and White's (2005) and Lin, Chan, & van Aalst's (2014) studies, students in the experimental group were engaged in additional teaching activities, that supplemented NOS instruction (e.g. self-monitoring strategy, self-assessment and integration of knowledge building pedagogy), which might have contributed to the observed differences between the students in the control and experimental groups.

In any case, the single most important conclusion that seems to emerge from the literature review in this area is, that the existence of a direct mechanism mediating between improved NOS understanding and conceptual understanding is neither well understood or theorized nor thoroughly explored by empirical studies. Given the rather small number of studies published in the literature that could potentially provide evidence about the existence (or lack) of a direct connection between NOS understanding and conceptual understanding (N=8), it can be said that this topic has still not been sufficiently explored to date. Another point that is evident from the mere inspection of the information provided in Table 1 is that the available research does not shed sufficient light into this area, since the evidence that has been reported is, at best, inconclusive in the sense that, overall, the studies report mixed results. Thus, it would make sense to argue for (1) the need to engage in theoretical discourse so as to articulate the viability of such a direct mechanism on theoretical grounds, and (2) the need to design and conduct experimental studies to shed some light on whether such a mechanism is indeed corroborated by empirical evidence. In the following, we focus on the first of these challenges.

EXPLORING THE VIABILITY OF A DIRECT MECHANISM BETWEEN NOS AND CONCEPTUAL UNDERSTANDING ON THEORETICAL GROUNDS

Conventionally, conceptual understanding is conceived of as facility with disciplinary content knowledge which, in physics for example, entails the competent application of physical concepts, laws and principles for the analysis of the operation of physical systems (e.g. McDermott, Shaffer & Rosenquist, 1996). Incidentally, this definition seems to be consistent with how conceptual understanding is defined in the publications that were reviewed for the purpose of this synopsis, despite the nuanced operationalizations in the various studies. One critically important question in this context is the following: would it be reasonable to assume a direct mechanism mediating between NOS and conceptual understanding? Our position sets out from the premise that it is not readily apparent how improved understanding of NOS would *directly* put one in a better position in terms of facility with content knowledge. For instance, it is not easy to come up with a direct causal mechanism that could plausibly account for how improved understanding of a specific aspect of NOS (e.g., increased awareness of the tentative nature of scientific theories) could also directly induce corresponding learning gains in terms of one's ability to competently invoke conceptual tools for analyzing the operation of phenomena/systems. Interestingly, this argument could also flow in the reverse direction: improved acquaintance with disciplinary content knowledge and quantitative analysis of physical systems does not automatically induce improvement in NOS understanding. In other words, if a student comes to understand how a system of magnetized objects operates it does not immediately follow that s/he has gained any insights into the nature of science. Actually, this lies at the heart of the well-established position that NOS understanding does not seem to emerge spontaneously as a by-product of conventional content-intensive instruction; rather it requires explicit teaching treatment (Bell, Matkins & Gansneder, 2011; Hanuscin et al., 2006).

RECONSIDERING THE FOCUS OF THE DIRECT MECHANISM: WHICH ASPECT OF CONCEPTUAL UNDERSTANDING MAY BE IMPACTED BY NOS UNDERSTANDING?

The reader might be tempted to conclude that we are actually rejecting, on theoretical grounds, the possibility of a direct connection between NOS understanding and conceptual understanding. This is not the case. What we do suggest is that there might not be convincing theoretical arguments in support of such a direct mechanism when conceptual

understanding is reduced to the substantive side of content knowledge, which also results in a lack of studies exploring such direct mechanism. At the same time, we also argue that the lack of an apparent direct mechanism between NOS understanding and conceptual understanding could be an outcome of reliance on this narrow definition. Papadouris and Constantinou (2017) have offered a theoretical elaboration of conceptual understanding centered on the position that its definition could (and should) be usefully broadened to reflect a more holistic approach that integrates the substantive side of content knowledge with its epistemological/ontological underpinnings³. To clarify the distinction between these two components of conceptual understanding, the substantive side relates to the ability to competently draw on the appropriate concepts in analyzing the operation of physical systems. On the other hand, facility with the epistemological/ontological dimensions of content knowledge refers to one's understanding of ideas such as the ontological status⁴ and the epistemic value of the various constructs of disciplinary content knowledge (Bächtold & Guedj, 2014; Papadouris & Constantinou, 2017). To put this in a specific context, in the case of electrostatic phenomena, the substantive side would involve one's ability to reason with the notion of the electric field to make predictions about the operation of a charge distribution whereas the epistemological/ontological side would involve the appreciation of the idea that the electric field is an invented theoretical/mathematical construct, rather than a physical object, intended to facilitate the interpretation of interactions at a distance. We argue that such epistemological and ontological aspects of science content are clearly epistemology-based, but are different from what is framed as general NOS understanding (see e.g. Lederman, 2007), or epistemological beliefs (see e.g. Schommer, 1993). An understanding of such epistemological and ontological aspects would impact the appreciation for the usefulness of specific science concepts. While knowledge about disciplinary content can enable students to engage in problems where the approach is clearly set (i.e. it is clear which concept the students are supposed to use to solve the problem), it might not be sufficient if the challenge is more open and allows for a multitude of possible approaches. In this case, appreciation for the usefulness of a

³ The demand to address epistemological and ontological aspects of science concepts in science education has been expressed before (e.g. Duschl, 1990; Driver et al., 1996, Erduran, Bravo, & Mamlok-Naaman, 2007). Papadouris and Constantinou (2017c), however, argue to include these aspects as distinct components of conceptual understanding, instead of regarding them as a (valuable) add-on to disciplinary content knowledge.

⁴ Ontology has received considerable attention in the science education literature research as a framework for accounting for students' conceptual difficulties (Chi, Slotta, & Leeuw, (1994); Slotta, Chi & Joram, (1995)).

concept is important for students to try to approach a problem utilizing that specific concept. Thus, when conceptual understanding is regarded as *facility* with disciplinary content knowledge – and not the mere knowledge itself – such appreciation and thus an understanding of epistemological/ontological aspects appears to be part of such conceptual understanding. A more elaborate discussion on this theoretical perspective to conceptual understanding is provided in Papadouris and Constantinou (2017).

We believe that this perspective taken to defining conceptual understanding is directly related to the extent to which it would be plausibly connected to NOS understanding through a direct mechanism. Indeed, there seems to be an apparent connection between NOS understanding and students' understanding of the epistemological/ontological side of content knowledge. For example, linking back to the example with the electric field, appreciating that this is an invented construct, rather than a mere physical object, rests on a series of premises that reflect various aspects of NOS, including the ideas that science involves both empirical and theoretical terms and building knowledge in science takes human creativity. In this light, it would make sense to argue that improved appreciation of NOS ideas could be meaningfully linked to increased awareness of the epistemological or ontological dimensions of content knowledge.

It should be stressed that the argument about the seemingly direct connection between an adequate view on NOS and conceptual understanding by means of the epistemological or ontological aspects of content knowledge is still in a nascent form and there is a need for further elaboration and scrutiny on both, theoretical and empirical grounds. In terms of theoretical elaboration, it is important to undertake a more systematic and thorough attempt to build a more rigorous account of this connection. In terms of empirical research, it should be useful to explore whether (and to what extent) this connection does manifest itself, through classroom-based research that embodies an appropriate research design. Michel and Neumann (2017) have undertaken an empirical study intended to contribute towards this direction in the context of energy, which suggested that students' NOS understanding seemed to have a positive effect on students' understanding of epistemological/ontological aspects of the energy concept. Clearly, there is a need for further empirical research to better understand and describe critical aspects of this connection.

3.6 CONCLUSIONS AND IMPLICATIONS

In the present article, we elaborated on theoretical and empirical grounds the potential connection between NOS understanding and conceptual understanding. The main purpose of the article was to consolidate and critically review what is known in the literature on possible mechanisms connecting NOS and conceptual understanding. In the following, we (1) summarize the key findings from our literature review (2) discuss ensuing implications for teaching and learning in science, and (3) elaborate on possible avenues for further research.

What does the literature provide on mechanisms connecting NOS and conceptual understanding?

As a starting point, we reviewed the rationale Driver et al. (1996) had given for the connection between NOS understanding and the acquisition of conceptual understanding in science. Most of the evidence and reasoning provided by Driver et al. (1996) supports rather indirect mechanisms, in which NOS understanding is likely to benefit conceptual understanding through mediating variables such as students' motivation, self-concept, or scientific reasoning skills. However, the arguments made by Driver and colleagues have often appeared in the literature as alluding to a rather direct connection, which implies that conceptual understanding might also directly benefit from enhanced understanding of NOS ideas (e.g. Matthews, 1997; McComas et al., 1998).

For both types of mechanism, we reviewed the relevant research and provided a summary of the theoretical rationales and empirical evidence presented in the literature. Figure 2 provides an overview of the potential mechanisms that we were able to identify and the extent to which they have been substantiated by empirical evidence. We identified several indirect mechanisms, which draw on a range of mediating affective/motivational (e.g. Baumert et al., 2000; Buehl & Alexander, 2005; Ho & Liang, 2015; Hofer, 1994; Lin et al., 2013; Tsai, 1998; Tsai et al., 2011; Urhahne & Hopf, 2004) and cognitive variables (e.g. Archila, 2015; Bell & Linn, 2000; Khishfe, 2012a, 2012b, 2014; Songer & Linn, 1991). Also, we found that most of them seem to be substantiated by sufficient empirical evidence (see Figure 2). Thus, implementing NOS instruction in science teaching seems to bear the potential to support learning of the science disciplinary content in the long term, by means of a number of learning variables. It should be noted that the identified

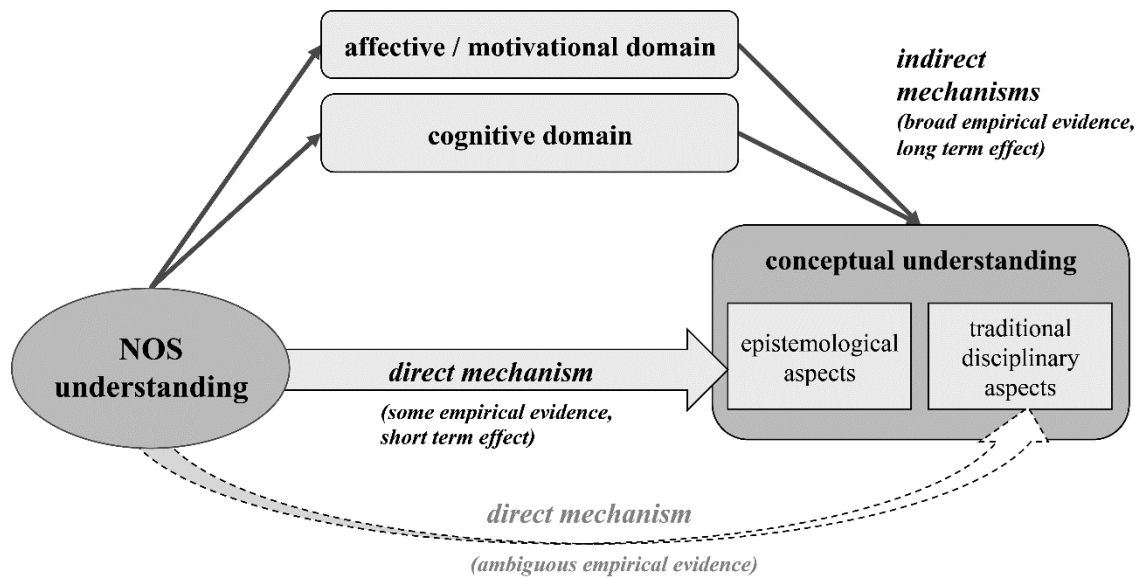


Figure 2: Overview of the potential mechanisms we were able to identify for a connection of NOS understanding and conceptual understanding.

connections do not necessarily have to be the most effective ways of promoting conceptual understanding. There might of course be other, more effective means to affect the specific learning-related variables. Our synopsis merely offers a review of what is known about potential indirect mechanisms linking NOS and conceptual understanding.

In contrast to the rich literature on indirect mechanisms, we found only eight studies (Irwin, 2000; Kim & Irving, 2010; Klopfer & Cooley, 1963; Lin et al., 2014; Michel & Neumann, 2017; Peters, 2012; Schwarz & White, 2005; Seker & Welsh, 2006) that employed a methodology that could provide insights into this topic, even though only one of these studies was designed to specifically address this question. What is even more interesting than the limited number of studies that could bear a connection to this topic, is that the empirical evidence that has been reported is somewhat ambiguous, with only three studies (Lin et al., 2014; Michel & Neumann, 2017; Peters, 2012) showing significant effects of NOS-oriented instruction on student learning gains regarding science content knowledge.

In summary, our literature review illustrated, that, while several studies have investigated the influence of NOS or scientific epistemological beliefs on factors which influence learning in general, such as learning strategies or motivation, far less ‘empirical evidence has been provided that links nature of science knowledge with content knowledge’ (Peters, 2012, p. 881).

As a next step, we therefore elaborated on a theoretical rationale for such a direct link (or mechanism) between NOS understanding and growth in conceptual understanding of science. From a theoretical perspective we find it difficult to build a compelling argument on how improvements on NOS could directly result in improving students' conceptual understanding, when the latter is limited to what is typically referred to as conceptual understanding. Put bluntly: Why should a student understanding the creative and subjective nature of scientific knowledge perform better in drawing the field lines of a permanent magnet? However, when conceptual understanding also includes epistemological and ontological aspects of science concepts and principles (e.g. the notion, that electric and magnetic fields are invented, theoretical constructs rather than physical objects), a student might better understand these aspects when understanding that all scientific knowledge is not objective facts that can be read from the book of nature but developed and devised by human beings. We therefore suggest broadening the current notion of conceptual understanding of scientific concepts by also taking into account their epistemological and ontological aspects.

What are the implications for science teaching and learning?

Our review of the literature suggests that NOS understanding holds a potential role as a promoter of science content learning, both through indirect and through direct mechanisms. For science instruction and for the integration of NOS in science curricula, the connection between NOS understanding and conceptual understanding – if supported by further evidence – would have great impact on the way we look at science teaching and learning.

The indirect mechanism, that is that conceptual understanding is impacted by NOS understanding mediated through learning-related factors, appears well-investigated and is broadly substantiated by empirical data. This implies that science instruction would benefit from an implementation of NOS as a distinct, independent science content, which is taught at different points of the curriculum. As our literature review shows, such implementation would then help to promote students' self-beliefs, interest and motivation in science, their learning strategies, reasoning and argumentation skills, metacognitive abilities, and problem-solving strategies, which would eventually impact students' learning of science content. Certainly, such implementation should happen in a contextualized and explicit manner (e.g. Clough, 2006). The size of its effects can hardly be estimated, as the

available empirical data is mostly correlational, and the expected impact would rather be long-term and thus hard to determine exactly.

The direct mechanism implies a substantial revisiting of what is meant by and taught as conceptual scientific knowledge. As outlined above (section 3.5) scientific understanding may benefit from NOS understanding if viewed as an integration of both, substantive and epistemological/ontological elements. Following our argumentation for such integration, epistemological and ontological aspects of relevant scientific concepts should be implemented in school science curricula. NOS aspects should thus be taught closely connected to the respective aspects of scientific content, in an integrated manner. Learning environments would then help students to ‘learn to view the subject matter they are being asked to learn through a lens of NOS’ (Lederman, 2007, p. 871). For the substantive side of conceptual understanding (i.e. disciplinary content aspects), our literature review shows rather ambiguous results of NOS implementation on students’ learning. For the epistemological/ontological side, however, Michel and Neumann’s (2017) study has shown that the effect of NOS understanding on students’ learning can be large and quite immediate.

What should be the focus of further research?

Future research should focus on unpacking the science education community’s common notion of ‘conceptual understanding’. Following our argumentation to regard epistemological and ontological aspects of scientific concepts as part of conceptual understanding (in accordance with Papadouris and Constantinou, 2017), epistemological and ontological aspects of science concepts need to be identified. As Osborne (2017) states, procedural and epistemic knowledge required to undertake practice must be defined and taught in conjunction with content knowledge. From an empirical point of view, the role of epistemological and ontological aspects requires further investigation: Are epistemological/ontological aspects independent from the traditional disciplinary aspects of scientific concepts (i.e. are these two distinct constructs from an empirical point of view), or do they conflate with each other? Which value do they add to a proper understanding and appreciation of the respective science concept? Is the connection between NOS understanding and conceptual understanding of science concepts dependent on the actual science concept investigated? For example, does the understanding of specific aspects of NOS enhance the understanding of certain scientific concepts, while in other cases this effect will not exist? To what extent do learning gains in epistemological/ontological aspects emerge

spontaneously, as a by-product of improved awareness of relevant NOS aspects and to which extent do they require specially designed teaching?

For many science concepts, epistemological aspects have been formulated and discussed. Regarding the concept of energy, for example, Richard Feynman argues that energy can be regarded as a purely theoretical, mathematical entity, which can be calculated for several different forms of energy, but which we do not really have knowledge about as to what it really is (Feynman et al., 1963). Coopersmith (2015) adds that energy is not a thing which has just been discovered, but that the underlying theoretical construct had to be forged in an ongoing process of putting together different ‘blocks’ to form a whole picture, thus making energy a somewhat ‘invented’ entity. In this sense, Papadouris and Constantinou (2011) argue that to understand and appreciate these epistemological aspects of energy: a sophisticated understanding of NOS seems important to serve as a framework which students can refer to when engaging in learning about energy and other scientific concepts. At the same time, students would be enabled to reflect on their ways of modelling these concepts and how this is in accordance with a realistic view of science and scientific knowledge. In a study conducted by Michel and Neumann (under review), it could be shown that by implementing relevant NOS aspects in a teaching unit about the energy concept, students’ understanding of the epistemological aspects of that concept could indeed be fostered, when compared to a unit that purely focuses on disciplinary content knowledge.

In other studies, however, epistemological aspects are rarely addressed in assessments of content knowledge or conceptual understanding. To potentially refine the definition of conceptual understanding for certain scientific concepts, it is important to develop and validate items for assessing their epistemological aspects and to investigate, whether these aspects support successful acquisition of conceptual understanding. Based on the outcome of further investigations, the content attached to “conceptual understanding” and the respective assessment approaches could be revisited and refined accordingly.

Finally, research seems necessary to further investigate the nature and strength of indirect and direct mechanisms through intervention studies, using quantitative and qualitative data. On the one hand, this research requires longitudinal studies, identifying the effect of indirect mechanisms in the long term. Our literature review shows that indirect mechanisms seem well-substantiated by existing data, but the review also reveals that there are

no exact estimates as to the size and sustainability of corresponding effects, which could inform teaching and curriculum development. Also, experimental or quasi-experimental studies are needed to investigate causal effects and establish respective claims, as most of the evidence at hand to date stems from correlational analyses. On the other hand, regarding the ambiguous results of our literature review concerning a potential direct mechanism, carefully designed intervention studies are needed, which focus on the effect of epistemologically-informed teaching units on students' conceptual understanding. Results of such studies could then help to inform curriculum development, the design of teaching materials, and the design and assessment of professional development for teachers.

4 PUBLIKATION 2: NATURE OF SCIENCE AND SCIENCE CONTENT LEARNING: THE RELATION BETWEEN STUDENTS' NATURE OF SCIENCE UNDERSTANDING AND THEIR LEARNING ABOUT THE CONCEPT OF ENERGY

Michel, H., & Neumann, I. (2017). Nature of science and science content learning: The relation between students' nature of science understanding and their learning about the concept of energy. *Science & Education*, 25(9-10), 951-975.

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 towards 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.

Keywords: *nature of science; energy teaching; energy learning; epistemological beliefs*

4.1 INTRODUCTION

Nature of science (NOS) has long been promoted as an important content of science education (Lederman, 2007; Lederman & Lederman, 2014; Schulz, 2014) and has consequently been included in multiple standard documents worldwide (McComas & Olson, 1998; e.g. NGSS Lead States, 2013). As early as about 20 years ago⁵, 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 & 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, Greca, and Freire (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 inconsistent⁶ 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

⁵ 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)

⁶ 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.

(e.g. the universal nature of the concept, as well as its predictive power; Bächtold & Guedj, 2014) and (b) there already exists some first evidence that addressing NOS helps in understanding such epistemic aspects (Papadouris & Constantinou, 2011).

4.2 THEORETICAL BACKGROUND

Nature of science (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, 1997a; Smith, Lederman, Bell, McComas & Clough, 1997), there is a strong consensus among researchers that science instruction – beside other 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 & 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 & Olson, 1998; NGSS Lead States, 2013; OECD, 2006; OECD, 2017; 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).

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 the nature of science (e.g. Brickhouse, 1990; Kang, Scharmann & Noh, 2005; see also Deng et al., 2011; Lederman, 2007) and approaches to teach about the nature of science (e.g. Akerson et al., 2010; Khishfe & Abd-El-Khalick, 2002; Lederman & Abd-El-Khalick, 1998), but also thoughts about how students' NOS understanding may affect their learning in science. For example, Sadler, Chambers, and Zeidler (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 the nature of science.

The literature also provides several empirical studies that investigated the effect of beliefs about science⁷ 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 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 & 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*

⁷ 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 & 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".

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, account 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 & Linn, 2000, Cavallo et al., 2003, Lin & 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 & 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.

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 & Warrington, 1985; Duit, 2014;

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; 2014; 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, 2014; 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). 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, 2014). 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 & 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 & Constantinou, 2011). To understand and appreciate these aspects, a sophisticated understanding of NOS seems important (Papadouris & 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 & Constantinou, 2014b). 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 (2014a) 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.

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 (2014a) 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

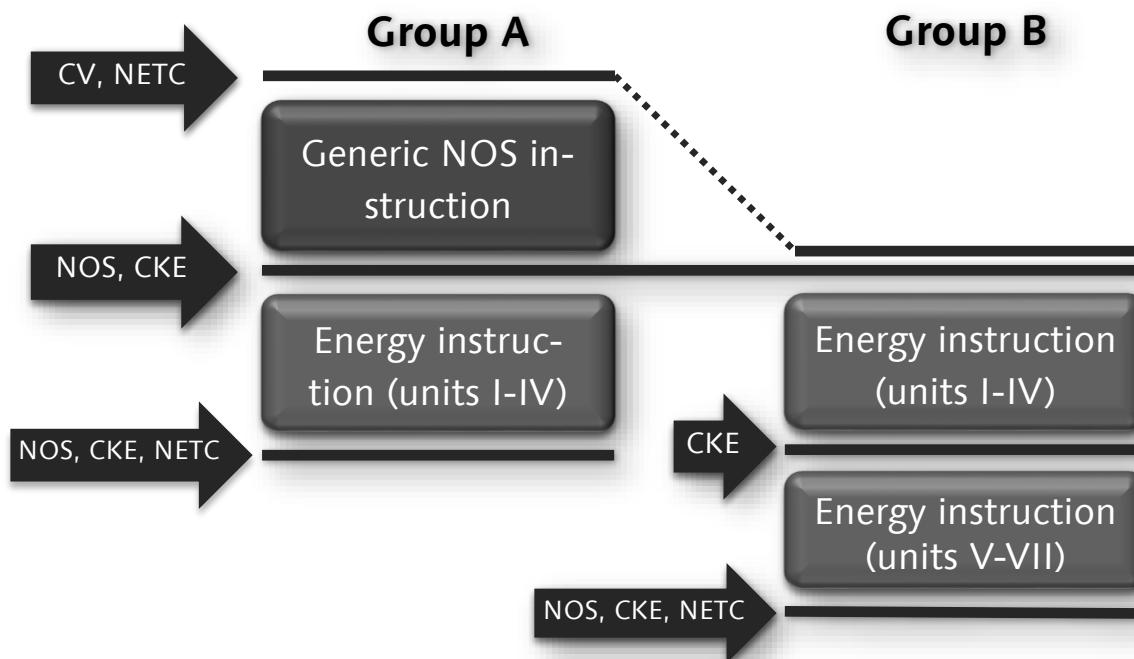


Figure 3: Study design: arrows show when tests are administered (CV = control variables, NETC = knowledge about nature of energy as a theoretical concept, NOS = knowledge about nature of science; CKE = content knowledge about energy).

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?

4.3 METHODS

To answer the research question, we performed a study in the context of a series of holiday science camps, each lasting three days in total. There were two distinct groups of students, group A and group B (see Figure 3). 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 minutes, or three

90-minutes 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-minutes schedule. All groups were taught by the same person, which is the first author of this article.

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 three days. Altogether, we ended up with 82 students (26 female), who attended the whole science camp, and who took all tests as shown in Figure 3. 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.

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, 2014; 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 towards 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 2.

The NOS unit, which only group A students were taught, was based on generic NOS activities (Lederman & Abd-El-Khalick, 1998), which were critically discussed in an explicit-reflective manner (see Akerson et al., 2000; Clough, 2006; Khishfe & 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 3. 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 & Constantinou, 2014a). The teaching units for both groups A and B had the same learning goals about energy, and employed similar teaching methods (see Table 4). 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.

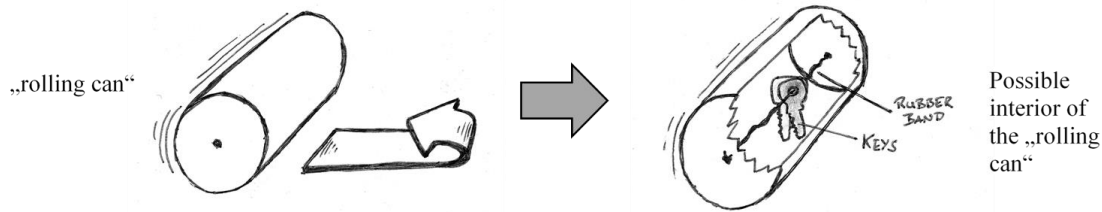
ASSESSMENT INSTRUMENTS

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

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 5). 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 2: Sample activities for energy units

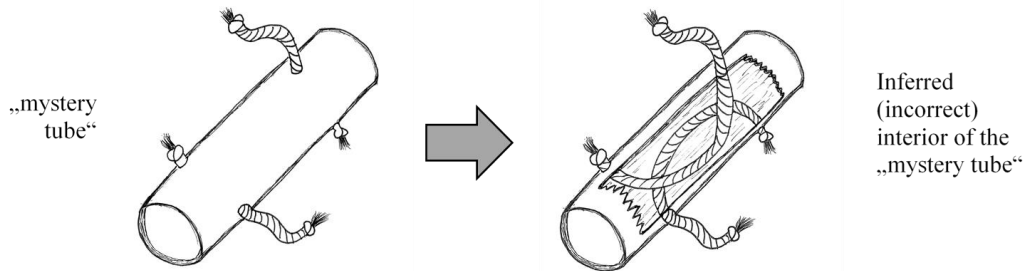
Sample Activity: The Rolling Can (Fortus et al. 2012)

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.

Activity	Energy aspect addressed	Activity description	Source
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)

Table 3: Sample activities for NOS units

Sample Activity: The Mystery Tube (Lederman & Abd-El-Khalick 1998)



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.

Activity	NOS aspect addressed	Activity description	Source
The Mystery Tube	Difference between observation and inference Role of creativity in science Tentativeness of scientific knowledge	See above. The activity is similar to the “Rolling Can” (see table 2), which was thought to potentially trigger students to apply their NOS understanding when approaching aspects of science content. There was, however, no direct connection drawn between the Tube and the Rolling Can activity.	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 foot-steps-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 (2014b)

Table 4: Pedagogical framework of the study.

	Group A	Group B
	Energy units I-IV: Traditional approach; content topics follow recommendations from science education research (energy forms, transformations, conservation)	
Approach	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

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, 2014; Neumann et al., 2013), the concept of energy also has some facets that are more epistemological in nature (Papadouris & 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 & 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 5). We employed items from already established instruments (Nordine, 2007; Papadouris & Constantinou, 2014a) 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 Figure 3). For data analysis, NETC items were scored using partial credits based on a scoring manual.

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 5. Whenever possible, we used items from already established instruments on energy (Bader, 2001; Nordine, 2007; Swackhamer, Dukerich & Hestenes, 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. 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 Figure 3). 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.

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, Schnabel & Baumert, 2000) and students' motivation (Fechner, 2009). To assess students' cognitive abilities, we employed a subscale of a well-established intelligence battery (Heller & 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 (Figure 3).

Table 5: 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)

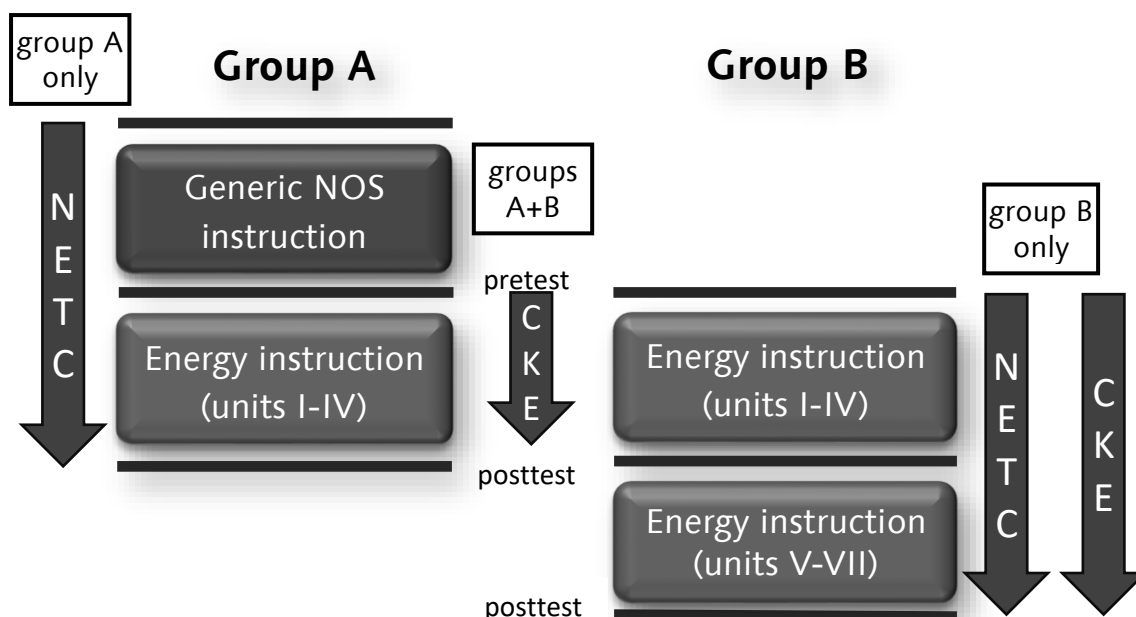


Figure 4: Performed analyses. NETC learning gains (indicated by the arrows) were analyzed for both groups separately, as their instruction between NETC pre- and posttest differed. As both groups received the same unit on energy, CKE learning gain from pretest to posttest I was analyzed for both groups collectively, while CKE learning gain from pretest to posttest II was analyzed for group B only.

4.4 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 don't 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, Miles & Field, 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 (pre- 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).

4.5 RESULTS

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 (for details on reliability and descriptive statistics, see the appendix). Table 6 shows the means for group A and group B prior to the teaching unit on energy. 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 Figure 3). 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.

Table 6: Group differences for variables before the first teaching unit about energy.

Variable	Mean Group A	Mean Group B	p-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

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.⁸

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 Figure 5), 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.

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 and measurement point as predictors for students' NETC score (see section 4.4). These analyses were performed separately for group A and B. For group A, the subsequent inclusion of both measurement point and NOS understanding

⁸ 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).

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 pre- and posttest. Figure 6 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 pre- and posttest. This is depicted in the incline of both regression graphs (pre- and posttest) in Figure 6. 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 pre- to posttest significantly differs in relation to their NOS understanding. Figure 6 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 and NOS understanding, significant interaction between NOS understanding and measurement point ($\chi^2(1) = 6.93, p < .01$), see Figure 7). 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.

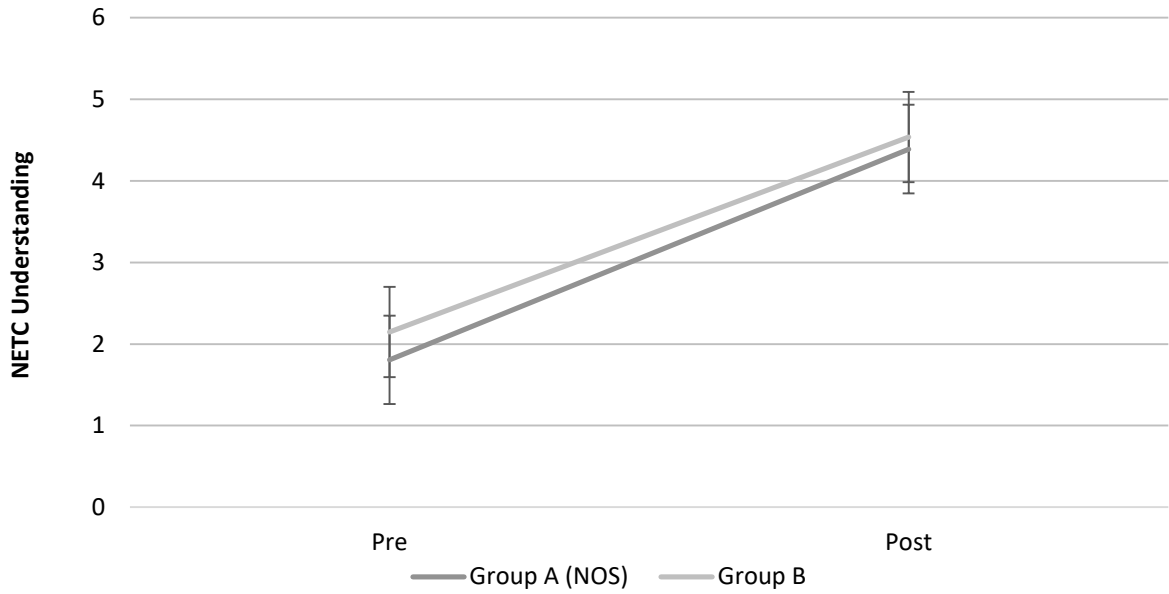


Figure 5: Group A students' understanding of the nature of energy as a theoretical concept (NETC) before and after the teaching unit in relation to their NOS understanding before the unit.

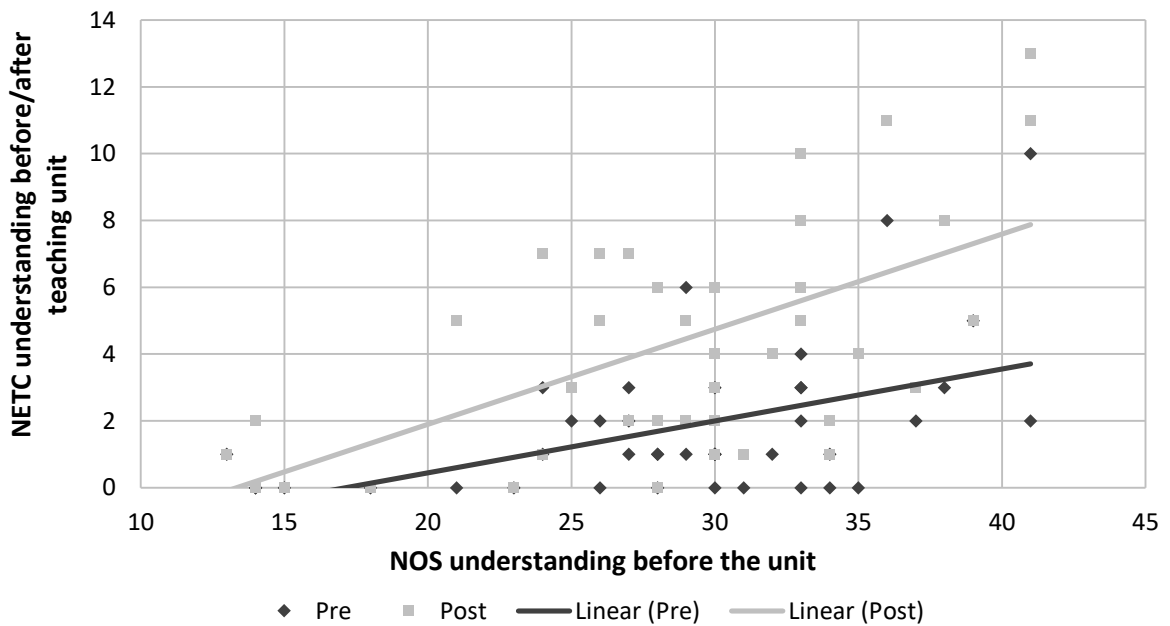


Figure 6: Students' understanding of the nature of energy as a theoretical concept (NETC) before and after the teaching unit.

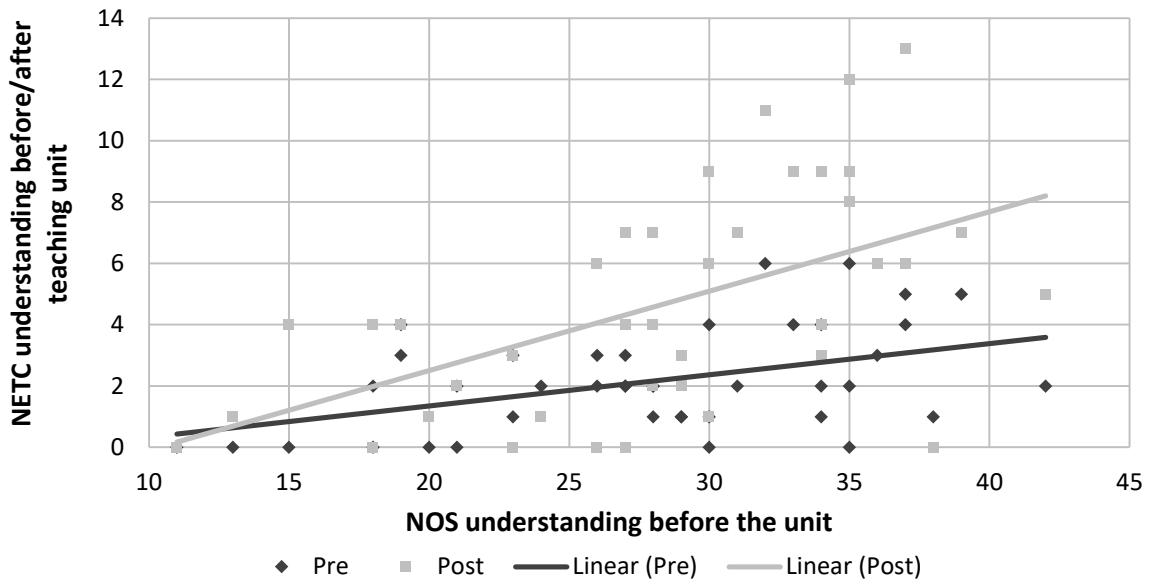


Figure 7: Group B students' understanding of the nature of energy as a theoretical concept before and after the teaching unit in relation to their NOS understanding before the unit.

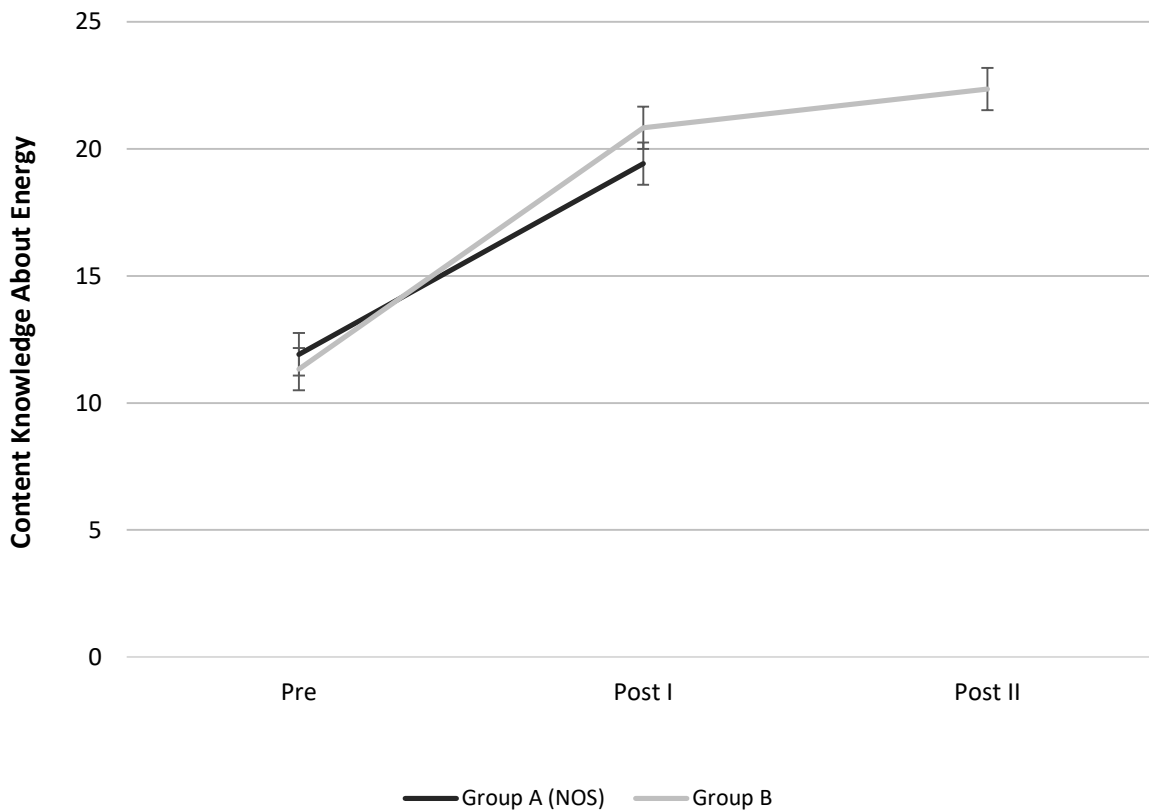


Figure 8: Group A and group B students' content knowledge about energy at the different measurement points.

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 of all 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 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 Figure 8) learning gain along units V through VII.

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 effects). Figure 9 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 Figure 9, 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 Figure 10, 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 trend-wise, as the learning gain for units V-VII was only small and not found to be significant). However, as we only conducted correlational analyses, valid causal claims cannot be established.

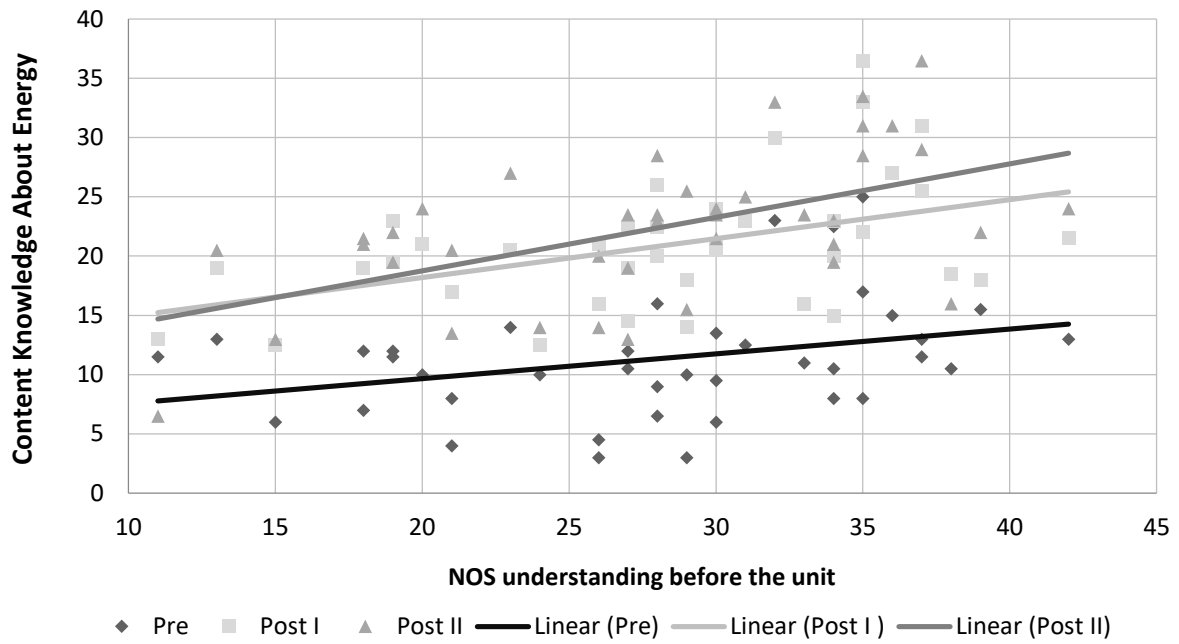


Figure 9: Students' content knowledge about energy before and after energy units 1-4 in relation to their NOS understanding.

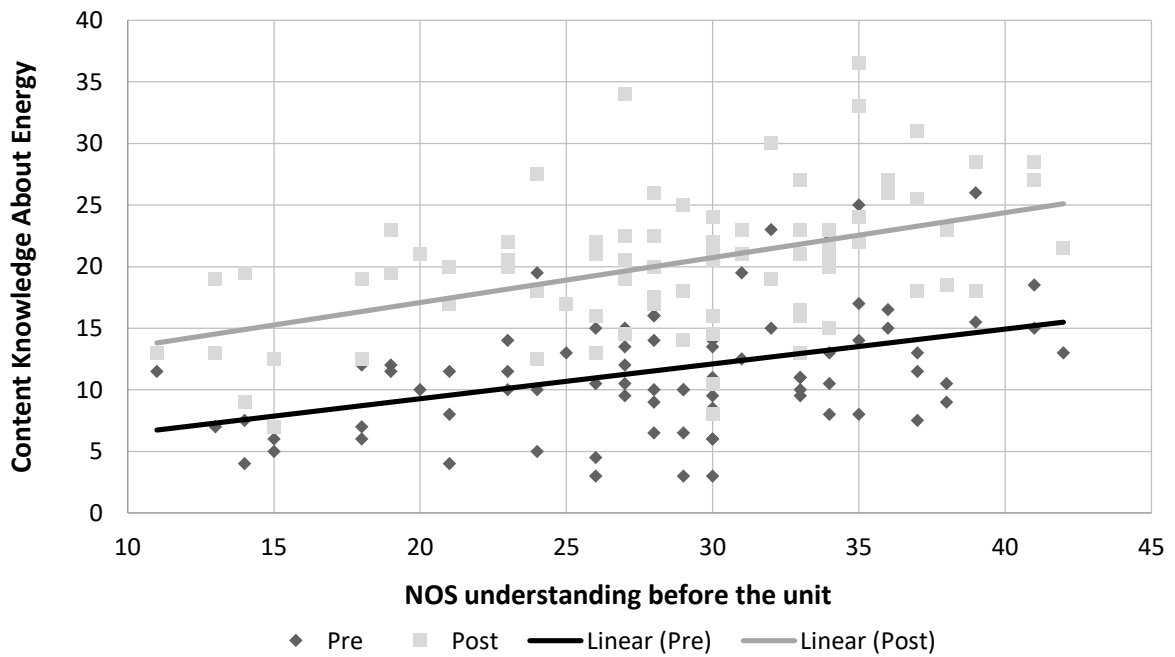


Figure 10: Group B students' content knowledge about energy before and after energy units 1-4 (Pre/Post I) and after energy units 5-7 (Post II) in relation to their NOS understanding.

4.6 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 (2014a), 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 (2014a), 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 percent 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.

4.7 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 minutes 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 grade 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 10 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 10). 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 minutes 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.

4.8 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 (2014a), 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 (2014a) 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 on 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.

5 PUBLIKATION 3: THEORETISCHE DENKMODELLE IM PHYSIKUNTERRICHT: EINE AN NATURE OF SCIENCE ORIENTIERTE HERANGEHENSWEISE AN DAS ENERGIEKONZEPT

Michel, H, & Neumann, I. (2014). Theoretische Denkmodelle im Physikunterricht: Eine an Nature of Science orientierte Herangehensweise an das Energiekonzept. *Praxis der Naturwissenschaften – Physik in der Schule* 63(8), 31-37.

5.1 ZIELE DER UNTERRICHTLICHEN VERMITTLUNG DES ENERGIEKONZEPTS

Auf Grund seiner fächerübergreifenden Bedeutung, seiner fundamentalen Stellung in verschiedenen physikalischen Teilgebieten und seines universalen Nutzens bei der Herangehensweise an verschiedene physikalische Probleme nimmt das Energiekonzept im Physikunterricht eine zentrale Rolle ein. Dies spiegelt sich nicht zuletzt darin wider, dass Energie in den Bildungsstandards eine fundamentale Funktion als eines von vier Basis Konzepten der Physik zugewiesen wurde. Aber auch außerhalb des Physikunterrichts, in gesellschaftlichen und ökologischen Debatten, in Medien und öffentlichen Diskussionen begegnen Schülerinnen und Schüler dem Begriff der Energie immer häufiger.

Dabei ist der Energiebegriff nicht immer eindeutig physikalisch konnotiert. Vielmehr wird „Energie“ im Alltag in völlig unterschiedlichen Bedeutungszusammenhängen verwendet. So kann man zum Beispiel „Energy Drinks“ kaufen oder in der Zeitung Debatten über die „Energieerzeugung“ oder den „Energieverbrauch“ verfolgen. Diese „Allgegenwärtigkeit der kontextuellen Bedeutungen des Begriffs Energie“ erschwert es Schülerinnen und Schülern, die Abstraktheit der Idee hinter dem physikalischen Energiekonzept sinnvoll zu fassen (Gerstberger & Muckenfuß, 2008, S. 43). Neben einem Fachverständnis der vier „Grundideen des Energiebegriffs“ – Energieformen und -umwandlung, Energietransport, Energieerhaltung und Energieentwertung (Duit, 1991) – sollte demnach ein Einführungsunterricht zu Energie im Sinne eines anschlussfähigen Verständnisses wie auch im Sinne einer Wissenschaftspropädeutik ein Verständnis von Status und Nutzen als theoretisches Denkmodell vermitteln. Eine solche Herangehensweise kann dann eine Abgrenzung des Energiebegriffs von Begriffen wie Kraft, Elektrizität oder anderen, leichter fassbaren und begreifbaren (da z. T. auch direkt erfahrbaren und messbaren) physikali-

schen Größen unterstützen, die Schülerinnen und Schülern oft schwerfällt. Dies kann gelingen, indem ein epistemologisch orientierter Zugang zur Energie gewählt wird, der zum einen den Nutzen des Energiekonzepts bei der Betrachtung naturwissenschaftlicher Probleme aufzeigt, zum anderen aber auch den Status als abstraktes und theoretisch entwickeltes Denkmodell diskutiert (Papadouris & Constantinou, 2011).

5.2 NATURE OF SCIENCE (NOS) IM PHYSIKUNTERRICHT

Die Vermittlung wissenschaftstheoretisch orientierter Inhalte im naturwissenschaftlichen Unterricht wird vor allem im englischsprachigen Raum als wichtiger Bestandteil einer naturwissenschaftlichen Allgemeinbildung angesehen und ist dort in Standards und Curricula verankert (McComas & Olson, 1998). In diesem Zusammenhang wird zwischen dem Wesen naturwissenschaftlichen Wissens und dem Wesen naturwissenschaftlicher Erkenntnisprozesse unterschieden (Schwartz et al., 2008).

Für die unterrichtliche Vermittlung des Wesens naturwissenschaftlichen Wissens werden insbesondere Status und Eigenschaften naturwissenschaftlicher Theorien und Gesetze als zentral angesehen. Lernende sollen demnach ein Verständnis des Unterschieds zwischen Beobachtungen und Schlussfolgerungen, sowie zwischen naturwissenschaftlichen Gesetzen und Theorien entwickeln und außerdem erkennen, dass naturwissenschaftliches Wissen auf empirischen Daten basiert, subjektiv und theoriegeladen, vorläufig und soziokulturell eingebettet und beeinflusst ist und die Genese solchen Wissens neben wissenschaftlicher Sorgfalt Vorstellungskraft und Kreativität erfordert (Lederman, 2007). Diese Aspekte spiegeln damit unter anderem die Sichtweise Karl Poppers wider, dass Theorien im Prinzip „frei erfunden“ werden und sich letztlich nicht beweisen, wohl aber durch entsprechende Experimente untermauern lassen (Popper, 1971). Auch Thomas S. Kuhns Vorstellung, neue Beobachtungen könnten Paradigmenwechsel einleiten und so zu einer Ablösung theoretischer Denkmodelle durch neue, elaboriertere führen, ist damit vereinbar (Kuhn, 1973).

Als Antwort auf die Frage, warum NOS im Unterricht thematisiert werden sollte, führen *Driver et al.* unter anderem ein sogenanntes „lernpsychologisches Argument“ an (Driver et al., 1996). Demnach kann ein breiteres NOS-Verständnis Lernende darin befördern, Fachinhalte in einen größeren Gesamtzusammenhang einzuordnen und somit Fachwissen

strukturiertes aufzunehmen. Um einen authentischen Zugang zu schaffen und auch zeitökonomischen Kriterien besser gerecht zu werden, sollte Unterricht über NOS dabei kontextualisiert, also eingebettet in einen Fachkontext erfolgen (Clough, 2006). NOS-Aspekte und Fachkontext sollten so nahtlos miteinander verwoben werden, dass Lernende den Bezug zwischen ihren eigenen Erfahrungen und naturwissenschaftlichen Denk- und Arbeitsweisen selbstständig herstellen und das Unterrichtsszenario nicht als unauthentisch wahrnehmen. Generische NOS-Aktivitäten, die nicht mit einem Fachkontext verknüpft sind, können allerdings als Einstieg in eine entsprechende Einheit sinnvoll sein, um NOS-Aspekte zunächst einzuführen, ohne Lernende durch die gleichzeitige Betrachtung fachlicher Inhalte kognitiv zu überfordern (Clough, 2006).

5.3 ENERGIE ALS NATURWISSENSCHAFTLICHES DENKMODELL

Zum Verständnis des physikalischen Energiebegriffs gehört insbesondere ein Verständnis des Prinzips der Energieerhaltung. Dieses Prinzip ist eines, das über einen Zeitraum von fast zwei Jahrhunderten entwickelt und immer weiter ausgeweitet wurde. Ausgehend von Johann Bernoullis Prinzip der „Erhaltung der lebendigen Kraft“ gab es eine Vielzahl von Erklärungsversuchen für vor allem mechanische und thermodynamische Probleme, unter anderem durch Joseph-Louis Lagrange, Thomas Young und Nicolas Carnot (Hoppe, 1965). Diese fortlaufende Überarbeitung und Weiterentwicklung verschiedener theoretischer Überlegungen zeigt anschaulich die Vorläufigkeit und Veränderlichkeit naturwissenschaftlichen Wissens. Nachdem der Arzt Robert Mayer 1842 die Energieerhaltung als grundlegendes Prinzip aller in der Physik beobachtbaren Phänomene postulierte, wurde er in der wissenschaftlichen Öffentlichkeit zunächst nicht ernst genommen, unter anderem wohl da er kein Physiker war (Hoppe, 1965). Als Hermann von Helmholtz und James Prescott Joule, die in der Wissenschaftswelt bereits einen hohen Ruf hatten, etwas später ähnliche Arbeiten veröffentlichten, erfuhren sie deutlich mehr Aufmerksamkeit. Diese historische Entwicklung des Prinzips der Energieerhaltung verdeutlicht, dass naturwissenschaftliches Wissen nicht völlig objektiv ist, sondern subjektiven Einflüssen unterliegt und dessen Entwicklung auch durch gesellschaftlichen Normen und Wertungen beeinflusst werden kann.

Darüber hinaus bietet der Energiebegriff aber auch auf Grund seines Status als abstraktes Denkmodell die Chance, das Wesen solcher theoretischer Wissens Elemente zu veranschaulichen. Durch den Vergleich mit anderen, mittlerweile überholten Theorien wird deutlich, dass eine Theorie dann besonders nutzbringend ist, wenn sie sich zur Erklärung und Voraussage vieler verschiedener Phänomene und Naturvorgänge eignet und wenn sie zu keinen beobachtbaren Vorgängen im Widerspruch steht. Unterricht über NOS kann also einen alternativen Zugang zum Energiebegriff ermöglichen, gleichzeitig bietet die Betrachtung der Energie viele Anknüpfungspunkte für eine Thematisierung von NOS.

5.4 GRUNDLAGEN EINER AN NATURE OF SCIENCE ORIENTIERTEN UNTERRICHTSEINHEIT ZU ENERGIE

Einen Ansatz, Energie und NOS miteinander verknüpft zu unterrichten, präsentieren Papadouris und Constantinou (2011), die diesen Ansatz bereits in Zypern erprobt haben. Über generische NOS-Aktivitäten werden hier zunächst Wesen und Nutzen theoretischer Denkmodelle thematisiert. Als Einstieg in die Energiethematik werden dann verschiedene Veränderungen physikalischer Systeme betrachtet und die Nützlichkeit einer universellen Theorie herausgearbeitet, die zur Erklärung aller beobachteten Phänomene gleichermaßen herangezogen werden kann. Mit dem Energiekonzept wird anschließend ein solches theoretisches Denkmodell eingeführt, dessen weitere Merkmale und Aspekte (wie Energieformen, -umwandlungen und das Prinzip der Energieerhaltung) sukzessive erarbeitet werden. Aus untersuchungstechnischen Gründen erfolgt die Erarbeitung der Energieaspekte bei Papadouris und Constantinou durch Aktivitäten am PC, um das Vorgehen der Lernenden direkt aufzeichnen und nachvollziehen zu können. Die Verknüpfung zwischen NOS- und Energie-Inhalten wurde durch gelenkte Diskurse der einzelnen Schülergruppen mit der Lehrperson hergestellt.

Die von Papadouris und Constantinou (2011) vorgeschlagene Einheit dient als Grundlage für einen hier vorgestellten Unterrichtsgang im deutschen Schulsystem. Konkret wurde eine Einheit für Schülerinnen und Schüler der 6. und 7. Jahrgangsstufe in Schleswig-Holstein entwickelt. Dazu wurde vor allem die Ausgestaltung der ersten Hälfte der Einheit, in der eine Einführung in die zu Grunde liegenden NOS-Aspekte erfolgt, in weiten Teilen von Papadouris und Constantinou (2011) übernommen und lediglich übersetzt und

leicht angepasst. Die anschließenden Aktivitäten am PC wurden im Rahmen einer großflächigen Überarbeitung der Einheit durch Schülerexperimente und Eigenaktivitäten in Kleingruppen ersetzt, wobei verknüpfende Klassengespräche die einzelnen Versuche miteinander verbinden und insgesamt eine adäquate Ergebnissicherung gewährleisten. Nach einer ersten Erprobung im Rahmen eines Ferienkurses wurden die Aktivitäten sowie der Unterrichtsverlauf erneut überarbeitet und aufeinander abgestimmt, wobei im Besonderen Wert auf eine kontinuierliche Verteilung von Verknüpfungspunkten zwischen NOS- und Energie-Aspekten gelegt wurde.

5.5 AUFBAU DER EINHEIT

Die vorgestellte Unterrichtseinheit ist eingebettet in den Kontext „Wissenschaft im Freizeitpark“. Dieser Kontext bietet zum einen eine alltagsnahe und für die Schülerinnen und Schüler spannende Kontextualisierung, zugleich aber auch die Möglichkeit, an Hand verschiedener Freizeitparkattraktionen in Schüler- und Lehrerversuchen viele verschiedene Formen und Aspekte von Energie zu betrachten. In der überarbeiteten Form umfasst die Einheit sechs Doppelstunden, wobei die ersten drei Doppelstunden vor allem auf ein Erarbeiten der zu Grunde liegenden NOS-Aspekte abzielen, welche dann in den folgenden drei Doppelstunden durch die Betrachtung des Energiebegriffs expliziert werden.

Zu Beginn der Unterrichtseinheit werden durch dekontextualisierte NOS-Aktivitäten Wesen und Eigenschaften wissenschaftlicher Beobachtungen und Schlussfolgerungen herausgearbeitet. Darauf aufbauend wird der Einfluss des Vorwissens bzw. die Theoriegeladenheit wissenschaftlicher Erkenntniswege thematisiert. Im anschließenden Diskurs wird herausgestellt, dass auch Wissenschaftler auf Basis ihres eigenen Vorwissens und der ihnen bekannten Informationen Vermutungen anstellen und Theorien erarbeiten. Naturwissenschaftliches Wissen hat damit auch immer eine subjektive Komponente. Um den Nutzen und gleichzeitig auch die Grenzen naturwissenschaftlicher Theorien aufzuzeigen, wird in der dritten Doppelstunde eine solche betrachtet und auf verschiedene Phänomene, die sich im Freizeitpark beobachten lassen, angewendet.

Nach der Betrachtung des Wesens theoretischer Denkmodelle im Allgemeinen wird nun der Übergang zum fachphysikalischen Teil der Einheit vollzogen, indem das Prinzip der Energieerhaltung als ein solches eingeführt wird. Als Einstieg gilt hierzu das gemeinsame Lesen und Analysieren eines Textes von Richard Feynman, in dem der Energiebegriff

über einen alltagsnahen Vergleich mit einer bestimmten Menge von Bauklötzen als abstrakte physikalische Größe eingeführt wird (Feynman et al., 1963). Nachdem Energie so als theoretisches Denkmodell eingeführt wurde, wird dieses sukzessive erweitert. Durch mehrere Versuchsreihen werden am Beispiel von Autoscooter, Achterbahn und Bungeesprung die Formen der Bewegungs-, Lage- und Spannenergie eingeführt und deren bestimmende physikalische Größen herausgestellt. Am Beispiel der Schiffsschaukel werden anschließend Energieumwandlungen betrachtet, hier zeigt sich der Nutzen des Prinzips der Energieerhaltung als erweiterbares theoretisches Denkmodell.

Im letzten Abschnitt der Unterrichtseinheit wird schließlich Energieentwertung thematisiert, indem etwa eine „unendlich laufende Achterbahn“ untersucht wird. Eine letzte Prüfung des Prinzips der Energieerhaltung erfolgt durch die Betrachtung scheinbarer Perpetuum mobiles, also etwa magnetischer Pendel, die durch eine Batterie am Schwingen gehalten werden. Im Diskurs wird herausgestellt, dass bei Energiezunahme innerhalb eines Systems Energie von außen zugeführt werden muss.

5.6 BEISPIELE FÜR VERKNÜPFENDE AKTIVITÄTEN

Nachfolgend werden ausgewählte Aktivitäten näher ausgeführt, die sich besonders für eine Verknüpfung von NOS- und Energieaspekten eignen. Im Rahmen der oben beschriebenen Unterrichtseinheit von sechs Doppelstunden wurden die folgenden Aktivitäten in der hier dargestellten Reihenfolge durchgeführt. Es ist durchaus denkbar, dass diese Aktivitäten auch losgelöst von der oben beschriebenen Unterrichtseinheit im schulischen Unterrichtsalltag genutzt werden. Dann ist jedoch darauf zu achten, dass das entsprechende Vorwissen bei den Schülerinnen und Schülern vorhanden ist (oder entsprechend nicht vorhanden ist, vgl. „Die unendlich laufende Achterbahn“).

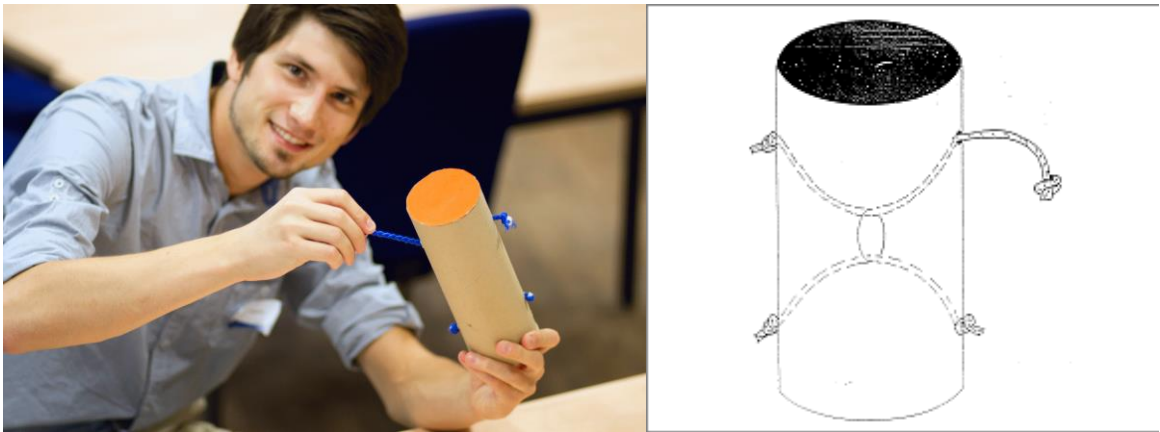


Abbildung 1: "Mystery Tube" (Skizze aus Lederman & Abd-El-Khalick, 1998)

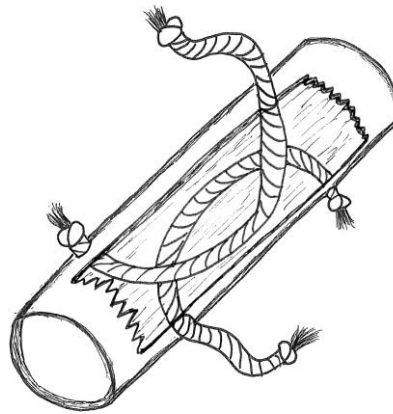


Abbildung 2: Vermuteter (falscher) Aufbau der "Mystery Tube"

MYSTERY TUBE UND ZAUBERDOSE

Die Genese naturwissenschaftlicher Theorien sowie die fehlende Möglichkeit, diese endgültig zu beweisen, lassen sich mit Hilfe der *Mystery Tube* und der *Zauberdose* nachvollziehen. Abbildung 1 zeigt den inneren Aufbau der *Mystery Tube* (aus Lederman & Abd-El-Khalick, 1998). Zieht man an einem der Enden, so wird ein anderes Ende in scheinbar zufälligem Muster in die Dose hineingezogen. Die Schülerinnen und Schüler werden gebeten, ihre Beobachtungen zu beschreiben (siehe Arbeitsblatt 1 im Anhang). Im Klassengespräch wird dann zwischen tatsächlichen Beobachtungen („Die Bänder werden in die Dose hineingezogen“) und etwaigen Schlussfolgerungen („Die Enden müssen irgendwie verbunden sein“) unterschieden. Die Wichtigkeit genauer und deutungsfreier Dokumen-

tation von Beobachtungen in der Wissenschaft wird dabei betont. Anschließend entwickeln die Lernenden eigene Theorien bzw. Entwürfe über den inneren Aufbau der *Mystery Tube* (siehe Abb. 2) und versuchen später, die Entwürfe der anderen Gruppen zu bewerten. Die Kategorien „richtig“ oder „falsch“ erweisen dabei schnell als unpassend, da ohne eine Auflösung in Form des Öffnens des Mechanismus die einzige Möglichkeit einer Überprüfung der ausgearbeiteten Vorschläge in einem Nachbau und einer anschließenden Betrachtung der Funktionsfähigkeit bestünde. Die Unmöglichkeit des Beweises naturwissenschaftlicher Theorien und Gesetze stellt dabei für die Schülerinnen und Schüler durchaus etwas Neues dar, ist jedoch nicht zuletzt auch für eine adäquate Betrachtung des Energiebegriffs von Bedeutung. Da Energie eine abstrakte Größe ist und sich weder anfassen noch direkt beobachten (bzw. messen) lässt, bleibt nur ein theoretischer Zugang zu diesem Konzept, der sich auf Beobachtungen natürlicher Phänomene und daraus gezogene Schlussfolgerungen stützt.

Weitere Anwendung findet diese Herangehensweise auch am Beispiel der *Zauberdose* (nach Fortus et al., 2012). Bei dieser handelt es sich um eine blickdichte Dose, in deren Innerem sich ein Gewicht (etwa ein Schlüsselbund) befindet, welches an einem Gummiband hängt, das die Dose quer durchzieht (siehe Abb. 3). Schiebt man die Dose in eine Richtung an, wird sie zunächst langsamer, dreht dann um und rollt bis zum Ursprungsort wieder zurück. Wieder werden die Schülerinnen und Schüler gebeten, ihre Beobachtungen zu formulieren und Theorien aufzustellen, die das Verhalten der Dose erklären. In der oben vorgestellten Unterrichtseinheit haben die Schülerinnen und Schüler zum Zeitpunkt dieser Aktivität bislang nur Bewegungs- und Lageenergie kennengelernt, sodass sich das Verhalten der Dose mit diesem Wissen zunächst nicht erklären lässt. Weil die Dose nach dem Umkehren jedoch zurückrollt, wird klar, dass die Energie nicht „verschwunden“ ist, sondern irgendwo im System gespeichert werden muss. Die Lernenden erkennen damit also die Notwendigkeit einer Erweiterung ihres theoretischen Denkmodells, in diesem Fall um die Form der Spannenergie.

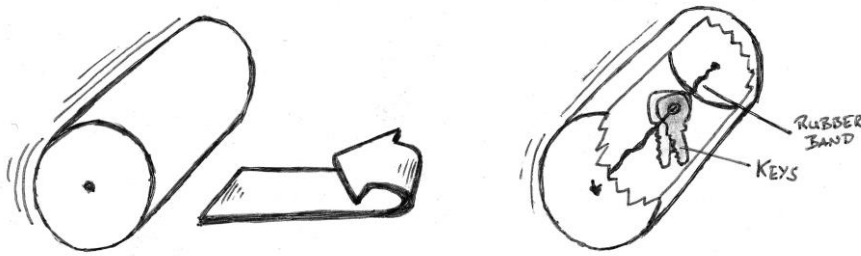


Abbildung 3: Verhalten (Beobachtung) und innerer Aufbau (Schlussfolgerung) der Zauberdose.

DIE BEWEGUNGSTHEORIE DES ARISTOTELES

Nutzen und Grenzen naturwissenschaftlicher Theorien können am Beispiel der „Theorie des natürlichen Ortes“ verdeutlicht werden. Diese Theorie, obwohl schon im vierten Jahrhundert vor Christus von Aristoteles formuliert, besaß bis ins Mittelalter hinein Geltung und bietet damit ein authentisches Beispiel für ein viel genutztes wissenschaftliches Denkmodell. Mittlerweile gilt sie jedoch als überholt; viele Phänomene, die mit Aristoteles Theorie erklärt werden konnten, werden heute mit Hilfe von Dichte, Gravitation und Schwerkraft betrachtet.

Bei der hier beschriebenen Aktivität (Arbeitsblatt 2a im Anhang) werden die Schülerinnen und Schüler zunächst in Bewegungstheorie von Aristoteles eingeführt. Mit Hilfe der Theorie lassen sich viele Phänomene recht einfach erklären, was die Schülerinnen und Schüler an Hand einfacher Freizeitpark-Attraktionen selbst unter Beweis stellen können. Hierdurch wird der Nutzen einer solchen Theorie verdeutlicht. In einem zweiten Schritt sollen die Schülerinnen und Schüler die Theorie von Aristoteles für die Erklärung weiterer Phänomene nutzen (Arbeitsblatt 2b im Anhang), wobei sie jedoch an die Grenzen der Theorie stoßen. Wechselnde Bewegungsrichtungen wie im Looping oder bei der Schiffschaukel lassen sich mit dem Streben nach einem „natürlichen Ort“ nicht erklären. Dieses Beispiel bietet damit auch die Möglichkeit, die Grenzen und die eventuell nötige Überarbeitung bzw. das Verwerfen von Theorien zu thematisieren.

Im Rahmen dieser Aktivität lohnt sich ein anschließender Diskurs darüber, dass theoretische Denkmodelle trotz ihrer prinzipiell nicht vorhandenen Beweisbarkeit nützliche Bestandteile naturwissenschaftlichen Wissens sind, da sich mit ihrer Hilfe verschiedene Phänomene, oft auch aus unterschiedlichen Domänen, erklären und vorhersagen lassen. Das Energiekonzept stellt ein solches universelles Denkmodell dar. Im Laufe der oben vorgestellten Unterrichtseinheit lernen die Schülerinnen und Schüler beispielsweise, viele der betrachteten Freizeitpark-Attraktionen mit Hilfe des Prinzips der Energieerhaltung zu betrachten und erfahren so den Nutzen dieses Prinzips. Die grundsätzliche Vorläufigkeit allen naturwissenschaftlichen Wissens wird ihnen aber ebenso bewusst gemacht. Dabei sollte jedoch deutlich werden, dass sich Denkmodelle wie das Prinzip der Energieerhaltung für die wissenschaftliche Arbeit bewähren können.

DIE „UNENDLICH LAUFENDE ACHTERBAHN“

In der oben beschriebenen Unterrichtseinheit waren Bewegungs- und Lageenergie sowie das Prinzip der Energieerhaltung zum Zeitpunkt dieser Aktivität bereits eingeführt. Außerdem hatten die Schülerinnen und Schüler die Energieerhaltung bereits genutzt, um damit ein einfaches System wie beispielsweise ein reibungsfreies Pendel zu erklären. Mit Hilfe der „unendlich laufenden Achterbahn“ (siehe Abb. 4) wird das Prinzip der Energieerhaltung dann in Frage gestellt. Dazu werden die Schülerinnen und Schüler gefragt, ob die gezeigte Achterbahn funktionieren kann, was nach deren derzeitigem Kenntnisstand – Bewegungs- und Lageenergie sind bekannt, innere Energie und weitere Formen noch nicht – der Fall sein sollte. Ein Ausprobieren der Bahn zeigt jedoch das Gegenteil. Der hier auftretende scheinbare Widerspruch zum vorausgesetzten Prinzip der Energieerhaltung kann schließlich im Diskurs aufgelöst werden, indem (wie auch bei der *Zauberdose*) die Notwendigkeit einer Erweiterung des theoretischen Denkmodells – in diesem Fall um zusätzliche Energieformen – herausgestellt wird. Hier kann *Feynmans* Analogie der Bauklötze (Feynman et al., 1963) angeführt werden, wobei expliziert wird, dass bei der Betrachtung von Phänomenen unter dem Aspekt der Energieerhaltung nicht zwangsläufig alle beteiligten Energieformen direkt offensichtlich sind, sich aber mit Hilfe der Theorie zumindest erarbeiten lässt, welcher Anteil der Energie noch identifiziert werden muss.



Abbildung 4: "Die unendlich laufende Achterbahn": Eine Murmel, am höchsten Punkt losgelassen, rollt auf Grund der Energieentwertung nicht wieder bis zum höchsten Punkt zurück.

ERFAHRUNGEN AUS DER ERPROBUNG DER EINHEIT

Eine erste Erprobung der vorgestellten Einheit fand im Rahmen eines Ferienkurses mit sechs Schülerinnen und Schülern der 6. und 7. Jahrgangsstufe statt. Um einen Zugang zum Energiebegriff über NOS zu ermöglichen, wurde hier insbesondere Wert darauf gelegt, dass die inhaltlichen Aspekte jeweils aufeinander aufbauen und auch diskursiv immer wieder miteinander verknüpft werden (Clough, 2006; Papadouris & Constantinou, 2011). Die Arbeit in Kleingruppen von drei Schülerinnen bzw. Schülern während der Experimentierphasen funktionierte gut, obgleich sich gerade bezüglich der NOS-Inhalte die anschließende Diskussion und Sicherung im Klassenverband als notwendig erwies. Wichtig für fruchtbare Unterrichtsgespräche war dabei eine gut funktionierende Diskussionskultur, die im Ferienkurs durch Kennenlernaktivitäten und diskussionsfördernde Spiele erreicht wurde. Im schulischen Kontext kann hier im Vorfeld mit der Klasse das naturwissenschaftliche Argumentieren geübt werden – dies kann jedoch auch gut im Rahmen der vorgestellten Einheit geschehen und an verschiedenen Stellen explizit thematisiert werden.

AUSBLICK

Die hier dargestellte Einheit wurde zunächst für einen Sommerkurs für Schülerinnen und Schüler der Jahrgangsstufen 6 und 7 entwickelt. Ein ähnlicher Unterricht, in dem Aspekte von NOS mit fachlichen Inhalten verknüpft werden, ist jedoch auch im schulischen Kontext denkbar. Darüber hinaus könnte die Einheit auch für ältere Schülerinnen und Schüler angepasst werden. Einerseits können dazu wie hier vorgestellt zunächst generische NOS-

Aktivitäten behandelt werden, die im Folgenden an Hand fachlicher Beispiele verdeutlicht und problematisiert werden, um etwa auf die generelle Abstraktheit naturwissenschaftlicher Theorien hinzuweisen. Denkbar ist aber auch ein Zugang, der sich an historischen Entwicklungen orientiert (vgl. Höttecke & Barth, 2011). Beispielsweise könnte die Geschichte Robert Mayers bei der Formulierung des Prinzips der Energieerhaltung betrachtet werden, um den subjektiven Charakter wissenschaftlicher Entwicklungen in den Fokus zu rücken.

Inwieweit sich ein Verständnis des Wesens theoretischer Denkmodelle auf einen besseren Zugang zu Fachwissen über Energie (also Wissen über Energieformen, -umwandlungen, -erhaltung und -entwertung) auswirkt, ist bislang noch eine nicht vollständig geklärte Frage. Dieser Zusammenhang ist daher der Fokus einer zurzeit laufenden Laborstudie mit ca. 90 Schülerinnen und Schülern im Rahmen des Ferienprojekts „Science Camp“ am IPN in Kiel. Im Rahmen der Studie werden außerdem die Entwicklung des NOS-Verständnisses und des Verständnisses von Energie als theoretisches Denkmodell über den Unterrichtszeitraum untersucht.

6 PUBLIKATION 4: INTEGRATING NOS AND SCIENCE CONTENT LEARNING: INSIGHTS FROM AN INTERVENTION STUDY

Michel, H., & Neumann, I. (under review). Integrating NOS and science content learning: Insights from an intervention study.

Abstract: Researchers have repeatedly claimed that NOS understanding would support students' efforts in gaining conceptual understanding of science concepts (e.g. Driver et al., 1996). However, only few studies have systematically investigated this potential effect and the interplay between NOS-oriented instruction and students' science content learning (Lederman, 2007). In the present study, an epistemologically informed teaching unit about energy was compared to a conventional teaching unit. In the treatment group, NOS and energy concept aspects were taught in an integrated manner, in the control group, NOS aspects were not focused on explicitly. 191 students from grades 10 to 13 participated in one of the two teaching units. Students' disciplinary content knowledge about energy (CKE), their understanding of epistemological aspects of energy (EAE), and their NOS understanding (general and context-specific) were assessed before and after the respective teaching unit. Results show significant learning gains for both groups regarding students' CKE, NOS understanding, and EAE understanding. There were no group differences in students' CKE gain, but the gains in NOS understanding and EAE were significantly higher for the treatment group than for the control group. Furthermore, students improved most in their NOS understanding regarding the context taught (i.e. energy), when compared to their NOS understanding regarding other contexts (evolution and atomic models). Overall, students that were engaged in the epistemologically informed teaching unit gained a more informed NOS understanding, which was also more consistent across contexts, than students engaged in the conventional teaching unit. These results imply that for students to develop a sound understanding of science concepts including their epistemological aspects, and to develop a durable and crosscutting understanding of NOS, these aspects should be explicitly integrated and discussed in addition to the disciplinary content attached.

Keywords: *nature of science; energy teaching; energy learning; epistemological beliefs*

6.1 INTRODUCTION

One of the main goals of science education is to provide people with sufficient scientific literacy, meaning that they are able to meaningfully engage in discussions, as well as decision-making processes concerning science related topics (Roberts, 2007). One important part of scientific literacy consists of understanding and being able to situationally apply science content knowledge. While this might seem sufficient to engage in everyday science-related problems, many scholars argue that for a deeper understanding of science and thus for a true scientific literacy, an understanding of the origin, status, and resilience of this disciplinary knowledge, about its inherent values and beliefs, holds importance as well (Driver et al., 1996; Lederman, 2006; Roberts, 2007; Schulz, 2014). This aspect of scientific literacy is commonly referred as Nature of Science (NOS) and has been promoted as a crucial learning outcome, for its inherent value as well as for its potential role as a prerequisite for learning disciplinary science content (Driver et al., 1996; Lederman, 2007).

In a literature-based rationale for the importance of including NOS in science instruction, Driver and colleagues (1996) provided a so-called ‘science learning argument’, concluding that NOS understanding might foster students’ ability to interrelate scientific concepts and thus coherently adopt science content knowledge. This argument, however, is mostly based on evidence regarding a positive influence of NOS understanding on students’ interest, motivation, self-concept, or other learning-related variables, rather than on the learning of disciplinary content knowledge directly (Michel, Papadouris, Neumann, Charalambous, & Constantinou, under review). Whether an understanding of such disciplinary content knowledge benefits from a sophisticated understanding of NOS thus remains a somewhat open question. Beyond disciplinary content aspects, several scholars have argued that epistemic and ontological aspects should be addressed in science education as well (e.g. Driver et al., 1996; Duschl, 1990; Erduran, Bravo & Mamlok-Naaman, 2007). Schulz (2014), for example, argues that science education should convey an adequate epistemological understanding about knowledge, truth and justification – aspects for which NOS understanding seems to be an important prerequisite. Papadouris und Constantinou (2017) conclude that epistemological aspects of science concepts form an important part of conceptual understanding and should thus be explicitly addressed in science education. Teixeira et al. (2012) provide a synthesis of studies that focus at this goal,

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. While a potential connection between NOS understanding and the disciplinary side of conceptual understanding (cf. Papadouris & Constantinou, 2017) is not really substantiated empirically (at least not in a direct manner), there appears to be a strong theoretical argument for a mutual interrelation between NOS aspects and epistemological aspects of science concepts, which is regarded as a substantial part of conceptual understanding as well (Papadouris & Constantinou, 2017).

Overall, there is a lack of empirical evidence regarding the relationship between NOS understanding and students' acquisition of conceptual understanding in science (Lederman, 2007; Papadouris & Constantinou, 2017; Peters, 2012). In a previous study investigating this relationship, we found that NOS understanding seemed indeed to be related to students' learning about some of the epistemological and disciplinary aspects of the energy concept during a teaching unit with middle school students (Michel & Neumann, 2017). With the present study, we aim to deeper investigate this relation by providing information about the impact of an epistemologically informed teaching unit (which concatenates NOS aspects, epistemological aspects, and traditional disciplinary aspects of the energy concept) on upper secondary school students' development of conceptual understanding regarding both NOS and science content.

6.2 THEORETICAL BACKGROUND

Understanding about NOS includes, among other aspects, ideas about the empirical and tentative nature of scientific knowledge, about the role of subjectivity and creativity in science, about the difference between observations and inference, as well as about the status and function of scientific theories and laws (Lederman, 2007; Lederman & Lederman, 2014). These or similar aspects of NOS are represented in several standard documents and are generally regarded as an important outcome of science education on all levels as a contribution to scientific literacy (Lederman, 2007; McComas & Olson, 1998; NGSS Lead States, 2013; OECD, 2006; OECD, 2017; Osborne et al., 2003). While recently some scholars have proposed alternative approaches towards conceptualizing NOS (e.g. Allchin, 2017; Dagher & Erduran, 2017; Hodson & Wong, 2017), which add to the ongoing discussion about how exactly to conceptualize NOS for science teaching, all of

the mentioned approaches share common aspects or features that they advocate, such as the tentative nature and socio-cultural embeddedness of scientific knowledge. In our approach, we do not aim at an all-encompassing, comprehensive, well-delineated conceptualization of NOS in general, but rather focus on certain aspects that seem related to aspects of the energy concept, and which are regarded substantial in the various conceptualizations of the concept.

Several studies reported on relations of NOS understanding to other learning-related factors, such as students' self-beliefs (e.g. Tsai et al., 2011), interest (e.g. Lin, Hong & Chen, 2013), learning strategies (e.g. Tsai, 1998), and other affective, motivational, and cognitive variables (e.g. Bell & Linn, 2000; Khishfe, 2012a). All of these variables are believed to foster science learning; as such, these studies substantiate an *indirect* relation of NOS and science content learning. Far fewer studies, however, focused on a *direct* mechanism, i.e. on the impact of NOS understanding on students' actual acquisition of science content specifically (for a conclusive synopsis of theoretical rationales and empirical evidence regarding potential mechanisms in which NOS understanding might influence conceptual understanding, see Michel et al., under review). Among the rare examples, Peters (2012), for example, found that during a teaching unit on electricity and magnetism, students who engaged in metacognitive prompts that explicitly addressed certain NOS aspects would outperform a control group without explicit NOS prompts, regarding both NOS understanding and content knowledge. Schwarz und White (2005) and Kim und Irving (2010), on the other hand, did not find such impact of NOS on the learning of genetics or force and motion, respectively. Overall, there is a lack of systematic investigations which clarify the relations between NOS instruction and learning of science concepts (Lederman, 2007; Peters, 2012).

INTEGRATED TEACHING OF NOS

Regarding NOS instruction, a lot of research has focused on how ideas about NOS can be taught and how NOS instruction can be realized for students of different ages (e.g. Akerson et al., 2010; Akerson & Donnelly, 2010; Khishfe & Abd-El-Khalick, 2002; Maurines & Beaufils, 2013). It appears to be important to teach NOS explicitly, as opposed to just engage students in science activities and expect them to derive the underlying epistemological ideas on their own (Khishfe & Abd-El-Khalick, 2002). At the same time,

even though NOS can be introduced and taught as a stand-alone topic in a decontextualized manner (see e.g. Lederman & Abd-El-Khalick, 1998), NOS should best be taught contextualized, i.e. set in a scientific context (Clough, 2006). On the one hand, science content aspects can be used to exemplify concrete manifestations of NOS aspects in everyday science, and on the other hand, NOS can help to connect different scientific disciplines or areas with each other by providing a joint framework, in order to make sense of science as a whole. Also, contextualized NOS instruction dismisses many teachers' concern that including NOS in science instruction would take away time from other important content (Clough, 2006). In the context of this study, we focus on *integrated* NOS and science content instruction, meaning that NOS is not only taught contextualized (in order to improve students' NOS learning), but that NOS and science content instruction are meaningfully interwoven to mutually support each other (thus supporting both students' NOS and science content learning).

To integrate NOS and science content instruction, several approaches can be used. First, NOS can be used as a vehicle to approach specific science concepts, e.g. by studying historical case studies and reflect on the way that scientific knowledge has been built (e.g. Maurines & Beaufils, 2013). This approach supports students to learn about important disciplinary aspects of that knowledge, as well as about the ontological status and epistemic value, at the same time. Second, students can reflect on their own scientific activities like experiments and group discussions to address certain aspects of NOS while elaborating disciplinary aspects of science content (Akerson et al., 2010; Clough, 2006). Finally, epistemological aspects of science concepts (such as the theoretical nature of the energy concept) can be used to focus on NOS and science content simultaneously and elaborate important notions of both (Papadouris & Constantinou, 2017).

Each scientific concept consists of particular disciplinary aspects (e.g. that there are several forms of energy), but also holds epistemological aspects (e.g., the theoretical nature or explanatory power of energy). To be included in science teaching, such epistemological aspects should be simple enough for students to understand, relatively uncontroversial, and productive, i.e. supporting students in making sense of disciplinary content knowledge (Papadouris & Constantinou, 2017). If they meet these criteria, epistemological aspects of science concepts can contribute to students' learning by promoting facility with content knowledge, helping students develop an informed epistemological stance

towards science learning as a whole, and at the same time enhancing students NOS understanding (Erduran et al., 2007; Papadouris & Constantinou, 2017). As such, epistemological aspects of science concepts are closely linked to NOS, so they can serve as contextualized examples of NOS aspects that can then be discussed and taken to a more general level. At the same time, teaching NOS aspects seems to be important as a prerequisite to help students understand and to appreciate students' understanding of epistemological aspects. According to the above reasoning, integrating NOS and science content instruction appears quite worthwhile and promising for efficient science education.

When NOS is taught in an integrated manner, students may attach the NOS aspects that they become aware of more to the context in which these aspects are taught, than to scientific knowledge in general. While Urhahne et al. (2011) found that students' context-specific and general conceptions about NOS share a mutual core, Khishfe (2017) observed that students responded inconsistently to different items regarding the same NOS aspects when these items were set in different contexts. For students' reasoning processes, however, as well as for their ability to use scientific ideas steadily in alternative settings, Khishfe argues that a consistent NOS understanding is important. Accordingly, she outlines the importance of exploring whether students develop well-structured and coherent ideas about science concepts and theories during science instruction, or whether their understanding remains fragmented and inconsistent. Thus, when investigating the effect of integrated NOS instruction on students' NOS understanding, it seems necessary to also examine whether this NOS understanding is dependent on the respective context, or whether students are able to transfer their understanding among different contexts.

LEARNING AND TEACHING ABOUT THE ENERGY CONCEPT

In order to investigate the effect of integrated NOS instruction on the understanding of science concepts, the targeted science concepts need to be appropriate in a sense that its epistemological aspects are relatively simple and uncontroversial, as well as productive (Papadouris & Constantinou, 2017). One scientific concept, which meets these criteria, is the concept of energy. The energy concept is generally considered a core idea in science on all levels, but is also a concept which students tend to have difficulties with (Driver & Warrington, 1985; Duit, 2014; Neumann et al., 2013). Some of these difficulties are linked to students' misconceptions about the epistemology, i.e. "the nature of knowledge, its scope, foundations, and validity" (Schulz, 2014, S. 1265), of the energy concept. They

often regard energy as a quasi-material substance, or some kind of fuel (Duit, 1987; 2014; Warren, 2007), rather than as a theoretical concept, which has been brought up by scientists to explain phenomena and make predictions (Duit, 2014). This naïve view, however, interferes with the way energy is conceptualized in schools and universities and eventually conveys an inadequate idea of what energy is (Bevilacqua, 2014; Coelho, 2014; Duit, 2014; Warren, 2007). Papadouris und Constantinou (2017) argue that a sound conceptual understanding of energy not only involves the disciplinary content knowledge attached to the concept (i.e. energy forms, transformation, transfer, conservation, and degradation, see also Duit, 2014), but also epistemological ideas about the status, purpose and value of the concept (Bächtold & Guedj, 2014).

Papadouris und Constantinou (2017) suggested three epistemological aspects of the energy concept which they deem important for an inclusion in science teaching. These aspects influence, and are mutually influenced by, certain aspects of NOS (see fig. 11).

First, energy is a *human-conceived* construct and cannot be seen or measured directly (Papadouris & Constantinou, 2017). This aspect has already been emphasized by Feynman et al. (1963), who argue that energy is a purely theoretical, mathematical entity, which can be calculated for a number of different forms of energy, while at the same time there is no knowledge about what energy really *is*. Energy is not a thing which has just been discovered, but for which the underlying theoretical construct had to be forged in an ongoing process of putting together different “blocks” of ideas to form a whole picture (Coopersmith, 2015). Understanding this human-conceived nature of energy might help students in dealing with the different terms regarding energy forms, while appreciating that these forms can be seen as different descriptions of the same theoretical entity (Papadouris & Constantinou, 2014b). This would aid them in understanding energy conservation and degradation, for both of which it is important to understand that “heat”, or thermal energy, also represents that very entity, and is not an indication of energy being “lost” during a process or phenomenon. At the same time, the human-conceived nature of energy – meaning that this knowledge provides a valuable framework for explaining and predicting the world and phenomena around us, but does not represent “the truth” about nature – can be discussed in the light of the general subjectivity and tentativeness of scientific knowledge, as well as its cultural embeddedness. This also means that scientists need creativity to infer scientific laws and theories from their observations. The

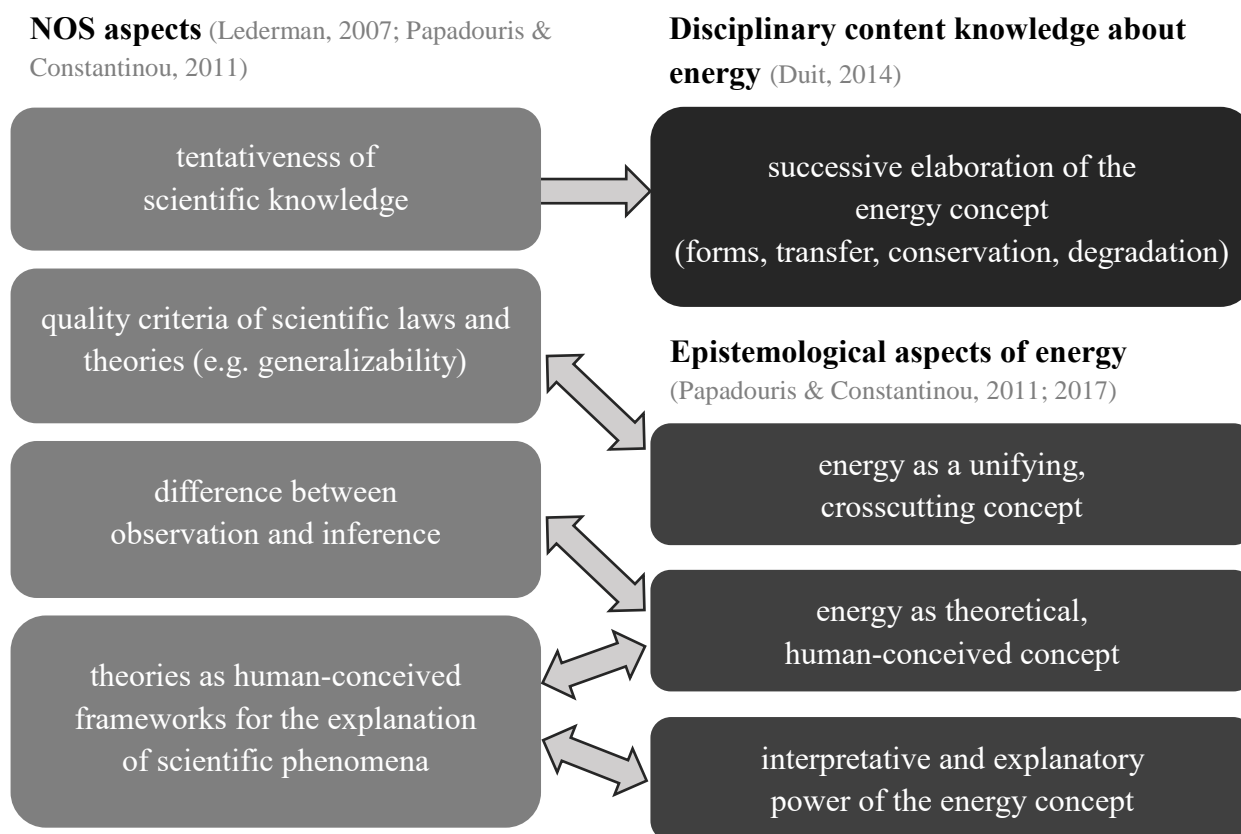


Figure 11: Theoretical framework: disciplinary content knowledge and epistemological aspects of energy and related NOS aspects. Arrows indicate, where interrelations between the understanding of certain aspects are theorized.

subjective, culturally embedded, and tentative nature of scientific knowledge, as well as the difference between observations and inferences and the role of creativity in science represent important aspects of NOS (Lederman, 2007; NGSS Lead States, 2013), that can be exemplified by discussing the human-conceived nature of energy, but which can also help to understand it

Second, energy is a *crosscutting* concept, applicable to different phenomena and used in various scientific disciplines, and is therefore unifying in nature. While scientific knowledge as a whole aims to be preferably generalizable, many scientific concepts are linked to a particular domain of phenomena. Energy, in contrast, can be applied to a broad variety of phenomena in almost every field and discipline of science and thus offers a unified approach towards many scientific problems (Arons, 1999; 2012). Appreciating such crosscutting perspective should enhance students' ability and likeliness to apply the energy concept to problems they encounter and use it as a framework to make sense of them (Papadouris & Constantinou, 2014b). For students to appreciate this aspect of

energy, it should be explicitly discussed, and energy should be set in comparison to other scientific concepts, which are not as unifying. In this context, quality criteria for scientific theories and laws (such as a high degree of generalizability) can be discussed as a component of NOS.

Third, the energy concept holds a significant *explanatory and predictive power* (Papadouris & Constantinou, 2017). While energy forms, transfer, and transformation provide interpretative accounts for describing and explaining scientific processes and phenomena, energy conservation and degradation can be used to make prediction as to how certain systems might develop. Energy conservation, in this sense, restricts a system's possible configurations (Duit, 2014; Feynman et al., 1963), while energy degradation allows to make predictions of what is likely to occur, due to knowledge about the tendency of energy to degrade in quality in the course of physical processes (Papadouris & Constantinou, 2017). Similar to the crosscutting nature of energy, appreciating the explanatory power of the concept might increase the likeliness of students to resort to energy when engaging scientific phenomena. At the same time, the explanatory and predictive power of energy resemble important criteria that serve to judge the value of scientific concepts and theories on all levels, which also adds to the NOS aspect of understanding the nature of theories and laws, as well as their differences.

Overall, NOS aspects seem to be closely related to epistemological aspects of science concepts such as energy and could thus be an important prerequisite for students to draw upon (see fig. 11). At the same time, epistemological aspects can serve as examples to discuss and elaborate on the respective NOS aspects. Eventually, NOS understanding might not only support the learning of epistemological, but also of the disciplinary aspects of energy. Acknowledging that scientific knowledge is tentative, for example, might aid students in understanding their own learning processes and changes of ideas – and thus influence their learning strategies – as opposed to seeing scientific knowledge as an accumulation of facts (Driver et al., 1996). As energy is typically taught in a certain sequence (forms, transfer, conservation, degradation; cf. Duit, 1986), students might be more able to reflect that such learning pattern represents the way in which scientific knowledge is usually built (as it was for the energy concept, see Coopersmith 2015), and thus be more likely to adapt new ideas and aspects to their pre-existing understanding of the concept.

A teaching unit connecting energy aspects to aspects of NOS in a way that both concepts mutually promote each other has been suggested by Papadouris und Constantinou (2011). In this unit, NOS aspects are introduced using decontextualized activities and are later linked to activities focusing on energy aspects. Students are engaged in reflecting and discussing about the epistemological aspects of energy, while at the same time exploring disciplinary features of the concept. Based on qualitative data, the authors showed that the described unit successfully improved students' understanding of NOS and of the epistemological aspects of energy (Papadouris & Constantinou, 2014a). Building on this work, we conducted an intervention study in which we related middle school students' prior NOS understanding to their learning about disciplinary and epistemological aspects of the energy concept in the course of a teaching unit about energy, using quantitative data and inferential statistics (Michel & Neumann 2017). In this study, we found that higher NOS understanding was strongly related to students' gain in understanding about epistemological aspects of energy, which supports the findings of Papadouris und Constantinou's (2014a). Furthermore, for one group we found a statistically significant relation between students' NOS understanding before the unit and their gain in understanding about disciplinary aspects of energy, which mainly related to their learning about energy degradation – an aspect that is highly relevant when students are supposed to transfer their knowledge about energy in idealized systems to everyday science processes and phenomena. Despite these promising results, it remains unclear to what extent integrated instruction about NOS and science content can improve students' learning about the energy concept – its disciplinary and epistemological aspects – while at the same time conveying a proper understanding of NOS.

RESEARCH QUESTIONS OF THE PRESENT STUDY

In this study, we aim to extend the empirical insights in the relations between NOS understanding and learning about the energy concept found in previous research (Michel & Neumann, 2017; Papadouris und Constantinou, (2014a). Using an epistemologically informed teaching approach that builds on the unit developed by Papadouris und Constantinou (2011), and comparing it to the results of a conventional teaching approach, we aim to address the following research questions: (1) How does an epistemologically informed unit about energy influence students' gain in conceptual understanding – regarding disciplinary and epistemological aspects of the energy concept – as compared to a conventional teaching approach? (2) How does such teaching unit influence students'

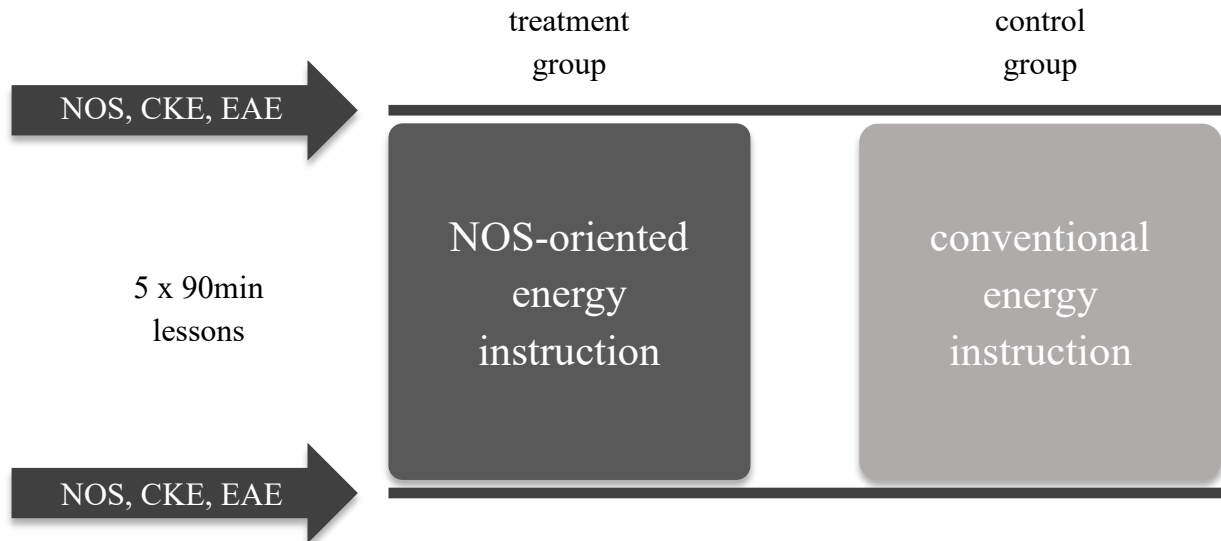


Figure 12: Study design: arrows show when tests are administered (NOS = nature of science understanding, CKE = disciplinary content knowledge about energy, EAE = understanding of epistemological aspects of energy).

NOS understanding? And (3) To what extent do students successfully transfer NOS understanding that they gained in the context of energy to other contexts, that is, to what extent does the epistemologically informed teaching approach promote students' well-structured and coherent understanding of NOS?

6.3 METHODS

To investigate the above research questions, we performed an intervention study, featuring two groups of students (see fig. 12). The students participated in one of two teaching units. Each unit included a total of five 90-minute lessons and spanned across two days. In the treatment group, students engaged in activities and discussions that elaborated on the disciplinary, as well as on the epistemological aspects of energy (EAE). In order to address EAE, aspects of NOS were introduced and explicitly connected to the respective aspects of the energy concept. In the control group, students engaged in similar activities about energy, but focused only on the disciplinary aspects of energy, without explicitly introducing and discussing EAE or NOS aspects.

SAMPLE

The sample for this study consisted of 191 students from grades 10-13 from upper secondary schools in Northern Germany. The students were drawn from 13 different classes that participated in a two-day physics course entitled “Energy in the Universe”, which was offered to schools and teachers in the area. The course was bundled into two days in total (due to organizational reasons), but apart from that followed the regular lesson schedule of the respective schools and used similar methods and group sizes as in regular teaching. In total, 247 students participated at least partly in the program. However, not all of the students were present on both intervention days or did not fully participate in all assessments. Also, some students gave only rather sparse responses (less than 75% of the items). There was plenty time for the students to fill out the assessment forms and we observed that for the students which showed a high number of missing answers, these were mostly evenly distributed throughout the whole test. Such response patterns rather indicate a general lack of motivation to fill out the test, than them not being able to do so in time, and thus we decided to omit these students’ data from the analysis, as we cannot fully infer these students’ understandings from the few answers they chose to give. The results presented here therefore draw on the responses of only these students who participated in all assessments and responded to at least 75% of the items of each assessment. We are confident that we did not systematically exclude low-achieving students from the analyses this way, as the answers they did provide are not systematically differing from the ones from the final sample. In the final sample, the treatment group consisted of 94 students (29 female and 65 male), which had an average grade level of 11.26 ($SD = 1.16$). The control group consisted of 97 students (25 female and 72 male), which had an average grade level of 11.58 ($SD = 1.01$).

INSTRUCTIONAL MATERIAL

The teaching units of both, treatment and control group, had the title “Energy in the Universe” and consisted of similar activities regarding the disciplinary aspects of energy (i.e. energy forms and transformation, transfer, conservation, and degradation; see e.g. Duit 2014). However, in the treatment group, NOS and EAE were discussed explicitly, while in the control group they were only implicitly accessible to the students.

Students in the treatment group received a unit, in which a teaching sequence developed by Papadouris und Constantinou (2011) was adapted. In this sequence, selected NOS aspects were introduced using generic NOS activities (Lederman & Abd-El-Khalick, 1998) and were then meaningfully concatenated with activities fostering students' understanding of the energy concept. For instance, students were presented a tube with four ropes attached to it, which, when pulled, behaved in a seemingly random pattern (the "mystery tube", Lederman & Abd-El-Khalick, 1998). Students were asked to come up with theories how the tube functions. Students learned that without looking inside the tube, the theories can only be judged by certain criteria, such as whether they explain the respective observations appropriately. Later on in the unit, this activity was then explicitly linked to a discussion about the postulation of the neutrino by Wolfgang Pauli, whose theory was in conflict with the one of Niels Bohr, who was questioning the law of energy conservation. Later, when Pauli's theory could explain certain observations which others could not, it was widely accepted, and the law of energy conservation continued to be one of the basic principles in science. Other historic examples and epistemic discourse (see Papadouris & Constantinou, 2011) were used to reflect on the generation and nature of scientific knowledge, as well as on aspects influencing scientific processes. During the unit, three epistemological aspects of the energy concept were explicitly discussed and connected to aspects of NOS: (1) energy – from an ontological viewpoint – is a human-conceived concept, i.e. it is an abstract theoretical construct, which has been brought up by scientists, rather than being a directly observable and measurable entity; (2) the energy concept can be used for approaching and explaining a broad variety of phenomena, i.e. it is crosscutting and transdisciplinary in nature; and (3) the energy concept serves as a powerful framework for the unified analysis of the operation of physical systems, i.e. it holds great epistemic value and explanatory power (see Bächtold & Guedj, 2014; Papadouris & Constantinou, 2011; 2017). NOS aspects that were emphasized throughout the unit (as they might potentially interconnect with students' learning of the respective EAE) were (1) the tentativeness of scientific knowledge, (2) quality criteria for scientific laws and theories, e.g. that they aim towards generalizability, and (3) the difference between observation and inference and the role of creativity in scientific processes, and (4) the aim and value of scientific theories to provide explanations and allow for the unified analysis of natural systems and phenomena (see fig. 11).

Students in the control group received a more conventional unit on energy. The activities and discussions addressing the disciplinary aspects of energy were the same as in the treatment group. As the concept of energy was applied in a number of different contexts and discussed in multiple contexts, the crosscutting nature of the energy concept was represented, but only implicitly. Similarly, the explanatory power of the energy concept was to a certain part represented in the discussions and activities that students engaged in. The human-conceived nature of the concept was represented in the fact that energy amounts were always calculated from other observed or given variables, implying that energy cannot be measured directly, thus being a purely theoretical entity. However, none of these epistemological aspects or corresponding NOS aspects, were explicitly addressed or named by the teacher throughout the unit. The additional lesson time (i.e. the time that was now not covered by discussing NOS and/or epistemological aspects) was used to engage students in additional activities and discussions about energy, so that the total instruction time was the same for both groups. All teaching units were taught by the same person, which is the first author of this article.

INSTRUMENTS

Before and after the respective teaching unit, all students were administered questionnaires assessing their understanding of disciplinary content knowledge about energy (CKE), their understanding of epistemological aspects of energy (EAE), and their NOS understanding (general and context-specific). To ensure comparability of the two groups, several control variables were assessed.

Understanding of epistemological aspects of energy (EAE). Students' understanding of the three aforementioned epistemological aspects of energy were assessed using a total of eight open-ended items, which were self-developed or adapted from Kang et al. (2005) and Papadouris and Constantinou (2014a). Originally, an item pool of 10 items had been used in a previous study (Michel & Neumann 2017), after which items were revised, removed, or rearranged according to item statistics, student answers, and recent theoretical considerations (e.g. Papadouris & Constantinou, 2017). All open-ended items were scored using a partial credit scoring manual. Sample items with exemplary answers from the pre and post assessment students' EAE understanding are shown in table 7.

Disciplinary content knowledge about energy (CKE). Assessment on energy understanding consisted of multiple choice and open-ended items, focusing on declarative and conceptual knowledge about energy. Each CKE item was addressing one aspect of the energy concept as suggested in the literature (e.g. Duit, 1986): (1) energy forms and transformation, (2) energy transfer, (3) energy conservation, or (4) energy degradation. Items were mostly taken from already established instruments on energy (Bader, 2001; Nordine, 2007; Swackhamer et al., 2005). In order to cover all aspects of CKE that were addressed in the teaching units, additional items were self-developed. The final assessment consisted of eight multiple-choice and 17 open-ended items. 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.

NOS understanding (NOS) and context-specific NOS understanding (CNOS). Understanding of the four selected NOS aspects was assessed using a total of 13 Likert-scale items, which were selected and adapted from established instruments by Kang et al. (2005), Kremer (2010), Liang et al. (2008), and Neumann (2011). Additional items were self-developed. Students were provided with statements about scientific knowledge (e.g. “Scientific theories can never ultimately be proven true”) and were then asked how much they agree to these statements on a seven-point scale. Six of the items were reversed, so that a strong agreement with the statement would count towards a naïve understanding of NOS. The answers to these items were accordingly recoded. From students’ answers to all NOS items, mean scores were calculated to allow for further analyses. In addition to assessing students’ general NOS understanding, we used seven of the 13 items in a context-specific form (e.g. “the law of energy conservation can never ultimately be proven true”). Each of the seven statements was set in three different contexts: energy, evolution, and atomic models to see whether there would be differences in students’ NOS understanding depending on the context.

Control variables. In order to examine the groups’ comparability, students’ motivation and cognitive abilities were assessed as control variables. For students’ motivation, a selection of seven Likert-scale items was used (Fechner, 2009). To assess students’ cognitive abilities, we employed a subscale of a well-established intelligence battery (Heller & Perleth, 2000). The used subscale focused on students’ non-verbal cognitive abilities

(figural analogies). Both control variables were assessed before the start of the respective teaching units.

6.4 RESULTS

Before analyzing students' development of conceptual understanding of energy and of NOS understanding throughout the respective teaching units, we evaluated the internal consistency of the employed assessment instruments and the comparability of the two groups (see table 8). For the CKE assessment, the internal consistency was found to be good (Cronbach's $\alpha = .83$); the assessment instruments for motivation ($\alpha = .71$), general NOS understanding ($\alpha = .78$) and contextualized NOS understanding ($\alpha = .79, .76,$ and $.75$ for the assessments of NOS in the contexts of energy, evolution, and atomic models, respectively) showed acceptable internal consistency values. For EAE, the eight items that were employed to assess the three different aspects showed somewhat low internal consistency (Cronbach's $\alpha = .54$). Given that epistemological aspects of energy are typically not addressed in regular school science courses, students probably have a rather fragmented understanding and thus might respond to the assessment items somewhat inconsistently. Furthermore, the low reliability of the EAE assessment could imply that an understanding of the different epistemological aspects may develop somewhat independently from each other, especially when not addressed explicitly. We will examine students' EAE understanding and learning gain in more depth, looking at all three epistemological aspects and how they develop over the course of the teaching units. In order to check for comparability of the two groups, we compared their pretest scores of all dependent variables that we assessed (CKE, EAE, NOS, CNOS), as well as of control variables that we assessed (motivation, cognitive abilities). For all of these variables, there were no significant differences between the groups before the respective teaching units ($p > .05$, see table 9). This indicates that the groups were equivalent and that group differences in CKE, EAE and NOS understanding can be traced back rather to the difference in instruction than to differences in individual knowledge or attitudes.

Table 7: Sample items and sample answers for EAE assessment.

EAE	Item Text	Student	Example Answer Pretest	Score	Example Answer Posttest	Score
Human-conceived nature of energy	<p>Explain your opinion towards the following statements: (1) "In science, there is no room for 'made-up' theories. Scientists had to directly observe and measure energy to establish it as a scientific concept" (2) "Energy has been 'made up' by scientists, without them directly observing or measuring it. In science, it is common to 'make up' theories to interpret phenomena." (<i>adapted from Kang, et al. 2005</i>)</p>	Student A (treatment group)	"The energy in our universe has not been invented, it exists and in our universe, there is a certain amount of energy, which stays the same. It merely takes different forms."	0	"Without creativity in the theories, it is not possible to achieve new insights. This implicates that something like energy was invented, but is nonetheless plausible within the system; and even if we cannot prove it [energy], it is accepted nevertheless."	2
		Student B (control group)	"It is possible to invent a theory. It should nonetheless be tried to be substantiated by an experiment."	1	"To find out today's definition of energy, several different theories were necessary back at the time."	0
Cross-cutting nature of energy	<p>The formulas 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? What value do they hope to gain by using the same notion? (<i>self-developed</i>)</p>	Student C (treatment group)	"Energy is transformed from one form into another and is not lost. The law of energy conservation applies."	1	"Connected to each other, can be transformed into each other. Further connections become apparent. Many phenomena can be explained by one explanation, simplified."	2
		Student D (control group)	"Similarities: Energy cannot vanish, only be transformed. Value: -"	1	"Understand connections (=value), Similarities: Can be transformed into each other."	2
Explanatory and predictive power	<p>How exactly can the energy conservation law and the principle of energy degradation be used to approach the phenomenon of a tennis ball bouncing on top of a basketball? (<i>self-developed</i>)</p>	Student E (treatment group)	<i>No answer provided</i>	0	"Position 3 can be excluded immediately, because the energy cannot become higher than it was at the starting point. Position 2 can be excluded as well, because parts of the energy degrade, thus the ball cannot reach the same height as at the start; it has to be position 1."	2
		Student F (control group)	"Energy conservation explains how one part of the basketball's energy is transferred to the tennis ball. Energy degradation plays a role in the form of deformation energy and drag."	0	"The total amount of energy is conserved in different forms. However, if only the kinetic energy of the basketball is considered, energy degradation occurs."	0

Table 8: Reliability for the used assessment instruments.

Variable	n (Items)	Cronbach's alpha
Motivation	7	.71
CKE	28	.83
EAE	8	.56
NOS	13	.78
CNOS-energy	7	.79
CNOS-evolution	7	.76
CNOS-atomic models	7	.75

Table 9: Group differences for variables before the teaching unit.

Variable	Treatment group mean	Control group mean	p-Value	Test Method
Motivation	4.07	4.05	.82	Independent t-test
CKE	10.02	10.53	.50	Independent t-test
EAE	3.84	4.01	.64	Independent t-test
NOS	4.53	4.51	.81	Independent t-test
CNOS-energy	3.85	3.90	.74	Independent t-test
CNOS-evolution	3.94	3.93	.97	Independent t-test
CNOS-atomic models	4.31	4.24	.67	Independent t-test

STUDENTS' LEARNING ABOUT ENERGY

To investigate the impact on students' gain in conceptual understanding about energy, we examined students' learning about disciplinary content knowledge (CKE) and about epistemological aspects of energy (EAE). We used repeated-measures ANOVAs to examine whether there were significant learning gains and to determine whether these learning gains differ significantly for the respective groups.

Content knowledge about energy (CKE). Figure 13 shows the results for both groups' average scores at the CKE assessment before and after the respective teaching units. A respective ANOVA did not show a significant difference in learning gains between the groups ($F(1,188) = 0.002$, $p > .05$). Furthermore, when looking at individual items, we did not find any significant difference in students' average gain in item score between the two groups. For both groups, there are significant learning gains regarding CKE ($p < .001$). The effect sizes were similarly high for both groups (treatment group: Cohen's $d = 0.98$, control group: $d = 0.97$).

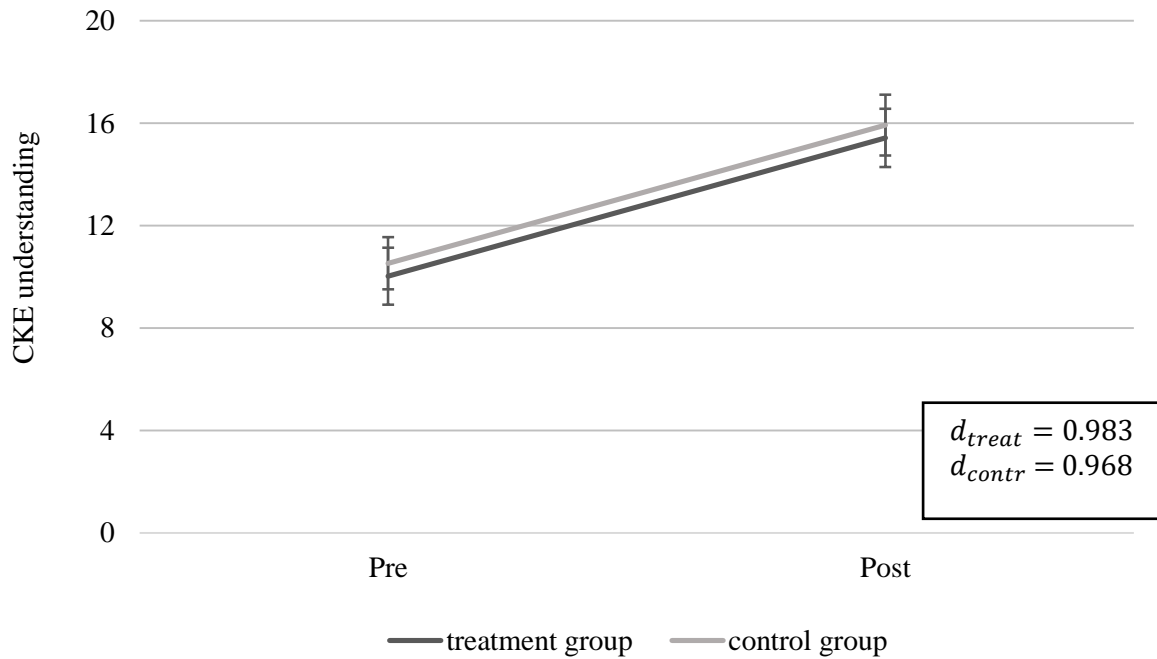


Figure 13: Means and 95% confidence intervals for students' understanding of disciplinary content knowledge about energy (CKE) before and after the teaching unit. Effect sizes (Cohen's d) are for intra-group learning gains.

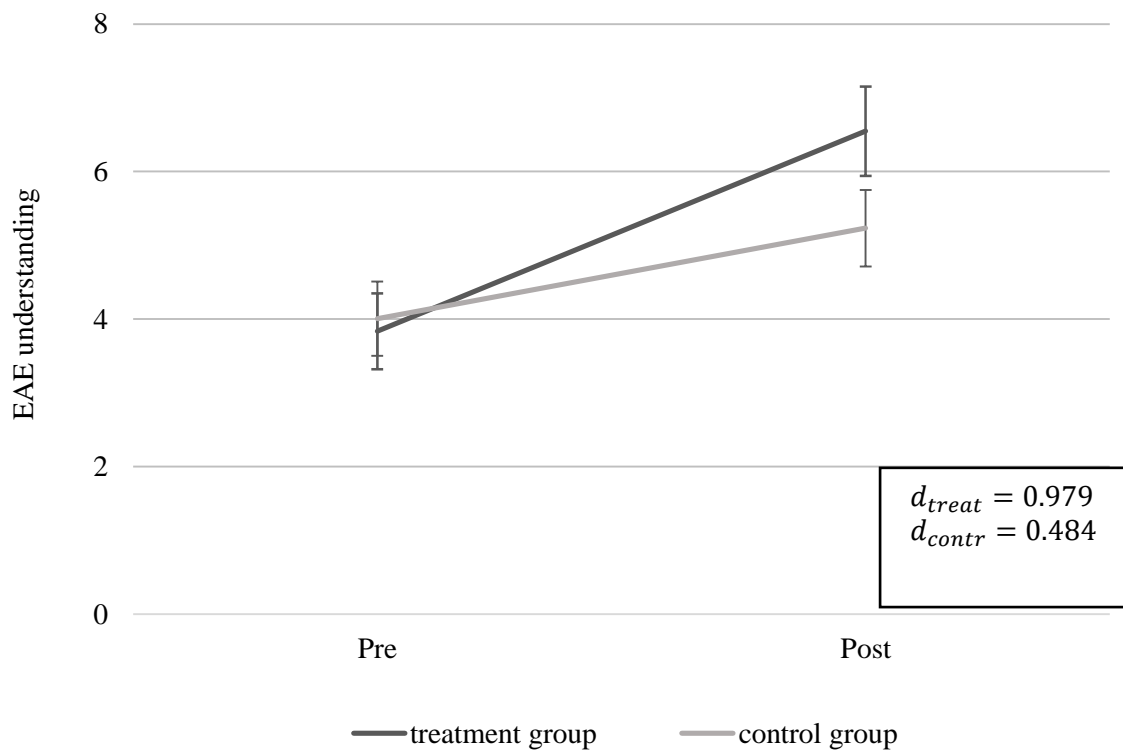


Figure 14: Means and 95% confidence intervals for students' understanding of epistemological aspects of energy (EAE) before and after the teaching unit. Effect sizes (Cohen's d) are for intra-group learning gains.

Epistemological aspects of energy (EAE). Students' understanding of EAE, as assessed before and after the respective teaching units, is shown in figure 14. A respective ANOVA shows a significant difference in students' average learning gain ($F(1,188) = 18.39, p < .001$). While students of both groups show significant learning gains ($p < .001$), the learning gain regarding EAE was much higher for the treatment group (effect size: $d = 0.98$) than for the control group ($d = 0.48$, see fig. 14). Interestingly, when looking at individual items, the EAE learning gain for students in the control group appears to mainly stem from items addressing the crosscutting nature of the energy concept, while they show only little gain in score on items focusing on the explanatory power and almost none on items enforcing the human-conceived nature of energy. Students in the treatment group, on the other hand, appear to gain understanding about all three EAE over the course of the unit. Table 7 displays exemplary responses prior and post intervention, for both treatment group and control group students. Before the intervention, both treatment and control group students mostly show a rather naïve or mixed understanding of EAE. While they are able to explicate a disciplinary understanding of energy (students A, C, D, and F, for example, mention energy transformation, different forms of energy, the law of energy conservation, or energy degradation), they show difficulties when asked to comment on the value of the concept (e.g. students C and D) Some students even neglect that energy is, after all, a human-conceived construct, but rather regard it as something objectively existent (student B). Furthermore, while they are able to apply the energy concept when approaching phenomena if asked to do so, they seem to have difficulties describing how exactly the concept can be used to formulate boundary conditions and thus predict the behavior of physical systems (students E and F). After the intervention, students of both groups seem more able to explicate the crosscutting nature of the energy concept and how it can be used to link different scientific phenomena (see students C and D). For the human-conceived nature of the concept, as well as for its explanatory and predictive power, control group students show little development in their understanding, their post-test answers often stay at a vague level or are restricted to disciplinary aspects (see, for example, students B and F). Treatment group students, however, seem much more able to illustrate these aspects after the intervention (see students A and E).

STUDENTS' LEARNING ABOUT NATURE OF SCIENCE

In addition to investigating students' gain in conceptual understanding about energy, we also examined the effect of the respective teaching units on their NOS understanding. First, we looked at students' understanding of the four selected NOS aspects in general, and second, on how their understanding of these NOS aspects (and gain in understanding) would differ when explicated in different contexts. Again, we performed repeated-measures ANOVAs to examine whether there were significant learning gains for both groups and to identify potential group differences regarding these learning gains.

General NOS understanding. Students' general understanding of the selected NOS aspects appeared to develop similar to their EAE understanding. There was a significant difference in learning gains between groups ($F(1,188) = 65.74, p < .001$), with the treatment group showing a much higher learning gain ($d = 1.64$) than the control group ($d = 0.48$, see fig. 15). While both groups showed a learning gain throughout the respective teaching unit ($p < .001$), the explicit NOS instruction in the integrated unit seemed to have greatly impacted students' NOS learning.

Context-specific NOS understanding (CNOS). Next to students' general (decontextualized) understanding of the selected NOS aspects, we assessed their NOS understanding when set in three different contexts: energy, evolution, and atomic models. Figure 6 and 7 show the results of these assessments before and after the teaching units for the treatment group (fig. 16) and the control group (fig. 17). Before the unit, students of both groups show a rather inconsistent view of NOS across contexts. Their ideas about NOS in the context of atomic models appear to be significantly more elaborated than in the contexts of evolution, or energy, respectively. Over the course of the unit, treatment group students showed significant learning gains regarding their NOS understanding in all three contexts. For energy (the context in which NOS was taught in the unit), however, this learning gain is significantly higher than for the other two contexts. The resulting NOS understanding after the unit appears to be more consistent along contexts, as there are no more significant differences for treatment group students' CNOS understanding in the three different contexts (fig. 16) For students in the control group, while they also show significant gains in context-specific NOS understanding in all three contexts after the unit, these learning gains are significantly lower than in the treatment group, and the resulting understanding of NOS remains somewhat inconsistent (fig. 17).

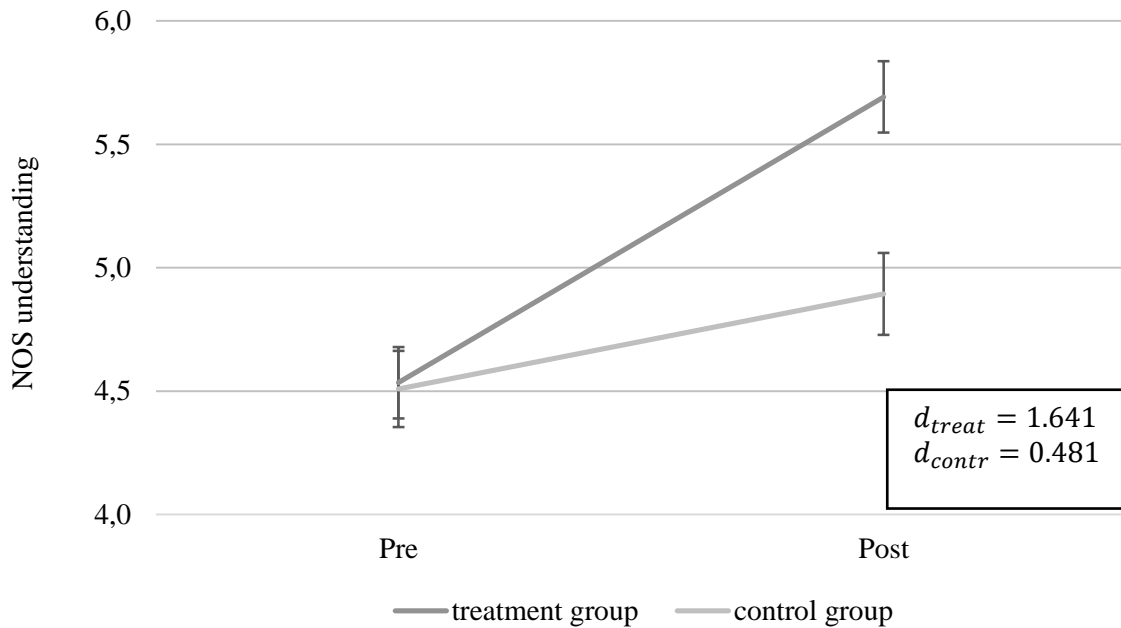


Figure 15: Means and 95% confidence intervals for students' nature of science understanding (NOS) before and after the teaching unit. A value of 4,0 represents a "mixed" understanding. Effect sizes (Cohen's d) are for intra-group learning gains.

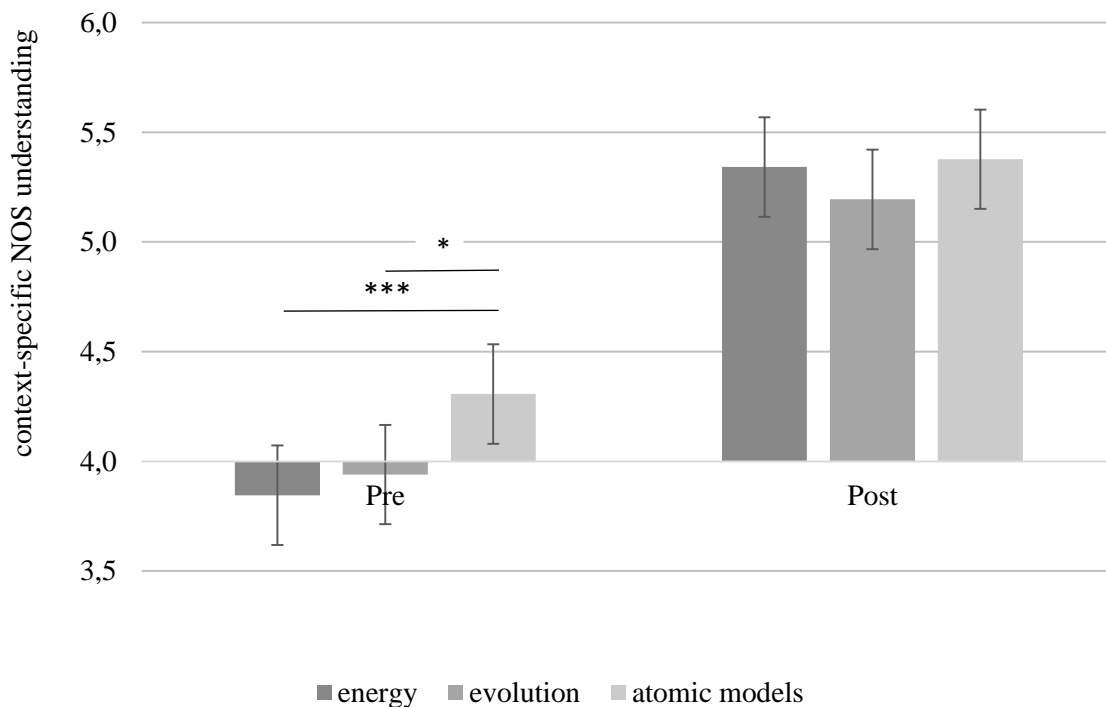


Figure 16: Means and 95% confidence intervals for treatment group students' context-specific nature of science understanding (CNOS) before and after the teaching unit. A value of 4,0 represents a "mixed" understanding. Asterisks indicate significant differences (ns: $p < .01$; * $p < .05$; ** $p < .01$; *** $p < .005$).

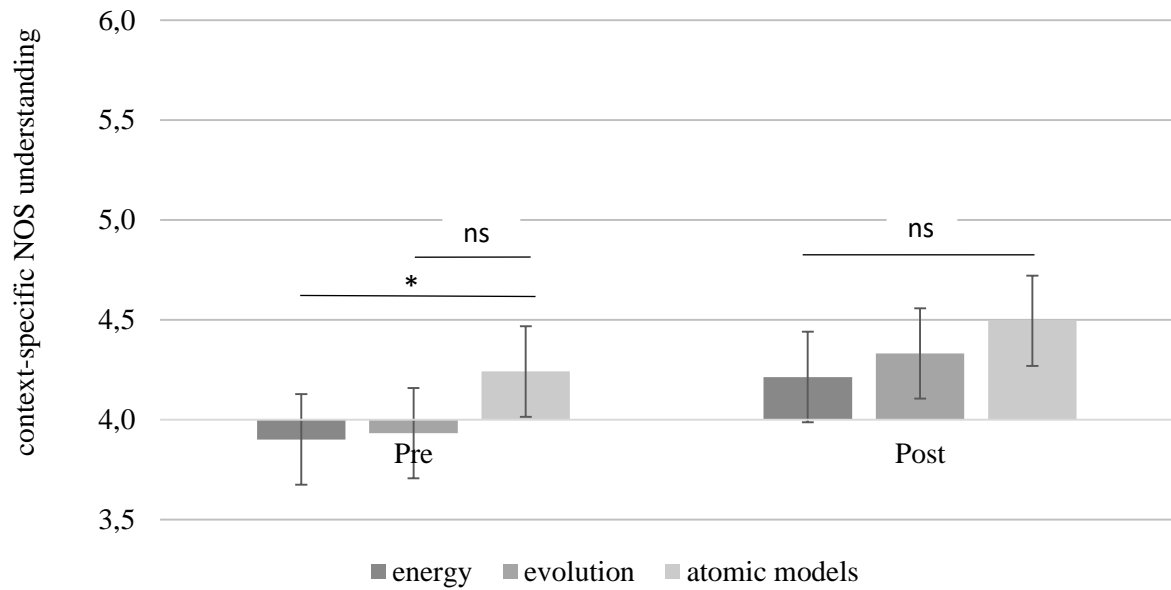


Figure 17: Means and 95% confidence intervals for control group students' context-specific nature of science understanding (CNOS) before and after the teaching unit. A value of 4,0 represents a "mixed" understanding. Asterisks indicate significant differences (ns: $p < .1$; * $p < .05$; ** $p < .01$; *** $p < .005$).

6.5 DISCUSSION

Based on these results, it appears that the epistemologically informed teaching unit (treatment group) was successful in enhancing students' conceptual understanding of energy (both the disciplinary and the epistemological aspects of the concept), and in conveying a more elaborated understanding of NOS at the same time. Compared to a conventional teaching unit on energy (control group) the integrated teaching approach showed several benefits.

The most defining characteristic of the integrated teaching unit is its direct and explicit approach towards epistemological aspects of energy. While students might gain an understanding of the ontological status and epistemic values of the concept implicitly, by utilizing it in various different settings and thereby learning to appreciate its cross-cutting nature and explanatory power, this seems to happen at a much faster rate when an explicit approach is taken. It appears that engaging in a broad variety of activities involving an energy-based approach towards a scientific question or phenomenon – as implemented in both groups – implicitly conveys an understanding of the crosscutting nature as well as of the explanatory and predictive power of the energy concept. Some students were, for example, able to express the value of utilizing the energy concept to build connections

between different phenomena, without having explicitly discussed this value throughout the teaching unit (table 7). An understanding of the human-conceived and theoretical nature of the concept, on the other hand, seemed hard to fully grasp for the students when not discussed explicitly, which is also represented in their answers to the open-ended writing tasks in the EAE assessment (see table 7). For a sound conceptual understanding of energy that includes its epistemological aspects, it seems thus important to explicitly incorporate epistemic discourse about the status, value and purpose of the energy concept, and to connect this to relevant aspects of NOS. Whether this is also true for concepts other than energy, should be subject to future debate and research.

Similarly, the treatment group, that explicitly engaged in activities and discourse about NOS aspects, and that meaningfully connected these NOS aspects to aspects of science content, showed a much higher learning gain on NOS than the control group. This is in line with prior research, which showed that NOS can be learned implicitly (as was also the case for control group students in this study), but is far more promoted by explicit instruction (e.g. Khishfe & Abd-El-Khalick, 2002). Especially for the human-conceived nature of scientific knowledge, the gain towards a more adequate understanding was much higher for the treatment group than for the control group, implying that this is an aspect that is especially difficult for students to comprehend when only addressed implicitly. However, there is a small but significant learning gain regarding NOS understanding for the control group, indicating that an adequate NOS understanding can partly be conveyed without explicitly emphasizing NOS aspects in science instruction. This, however, seems to happen at a much slower rate than when NOS aspects are explicitly addressed in the teaching unit. Furthermore, while students of both groups show a rather inconsistent NOS understanding across contexts before the teaching units (see fig. 16 and 17), the treatment groups' NOS understanding appears to be much more consistent after the unit, while the control group's context-specific NOS understanding remains inconsistent after instruction.

In addition to conveying an understanding of EAE and NOS, both teaching units had a high effect on students' CKE understanding. Integrating NOS aspects in instruction about energy seems thus not necessarily related to students' learning of disciplinary content knowledge, at least not in the short term of the two-day instructional unit. This seeming discrepancy with the findings of our first study (Michel & Neumann 2017) might be due

to the fact that in that study we focused on NOS *understanding* when examining the results, while in the present study we investigate the effect of NOS *instruction*, which might not have an immediate effect (although that NOS instruction would of course affect students' NOS understanding, as the results show as well), or it might be due to the higher age of the students (grades 10-13 as compared to grades 6-7 in the previous study). It could well be that the impact that NOS understanding has on students' learning of CKE is restricted to their early approaches towards the concept, and becomes less influential when students already gathered some conceptual understanding. The potential role of NOS for learning about disciplinary aspects of science concepts, and the question whether such relation relates more to a long-term mechanism (e.g. by raising students' interest in science), should thus remain a subject of further research.

6.6 LIMITATIONS

When interpreting the results of the study, certain limitations should be considered. First, the sample for the study might be positively biased towards students that are highly interested and show a higher motivation in science. Many of the groups that participated were consisting of students enrolled in a science profile, meaning that they would have more science classes than other students (who are enrolled in a language or social science profile). Thus, while the results can be interpreted as first insights in the effectiveness of a teaching approach integrating NOS and science content, they might not be completely representative for all students in general, but for those who are interested in science.

Another limitation stems from the design of the CKE assessment (disciplinary content knowledge about energy). The assessment was designed to cover students' understanding of energy forms, transformations, conservation, and degradation, as involved in the problems and phenomena that students focused on in both groups. The assessment items did not, however, focus specifically on the additional disciplinary content that was taught in the control group in the time that the treatment group spent on the NOS and EAE content. The restriction of the CKE assessment to content that was taught to both groups was done by design, so that the assessment time would not exceed timely restraints, but at the same time would allow to investigate whether the integrated teaching approach would impact students' learning of the shared content (which it did not). Thus, the result that after the teaching units, both groups on average show similar scores on the CKE assessment cannot

necessarily be interpreted as the control group not gaining more content knowledge despite having engaged with more disciplinary content. It might well be that – given items focusing specifically on the additional content – control group students might have scored higher than treatment group students on the CKE posttest.

6.7 CONCLUSIONS AND IMPLICATIONS

The presented study adds to the discussion about the relevance of NOS understanding for science education in general, and about its role for understanding the energy concept in particular. It also shows how epistemologically informed instruction about science concepts can be used to convey aspects of NOS and of science concepts. The results discussed above show that NOS-oriented instruction appears to be an adequate vehicle for helping students to fully grasp and make sense of the epistemological aspects of energy, which can be considered an important part of conceptual understanding (see Bächtold & Guedj, 2014; Papadouris & Constantinou, 2011). Thus, when science education aims to not only convey traditional disciplinary aspects of energy (e.g. knowing different forms; applying the law of energy conservation to particular phenomena) but also to let students perceive the value of energy as a central theoretical framework in science, which can be applied to manifold different phenomena and problems, an epistemologically informed approach towards the concept appears highly supportive (Papadouris & Constantinou, 2017). Our study indicates that for such teaching to be most effective, it should incorporate explicit instruction about NOS and the connections between NOS and science content aspects. For disciplinary content knowledge about energy, the epistemologically informed teaching unit appeared to also successfully support students learning, although for this side of conceptual understanding treatment group students' learning gain did not appear to be superior to that of students in a conventional unit about energy. This finding, however, only relates to a potential short-term effect of NOS instruction on learning about energy. In the long term, NOS understanding might indeed foster students' acquisition of conceptual understanding, e.g. through promoting students' motivation or their ability to coherently adopt new knowledge. Next to students' gain in conceptual understanding about energy, students receiving integrated NOS and science content instruction also appeared to develop a more consistent understanding of NOS across different contexts. The effect

of integrated NOS instruction on students' context-specific and general NOS understanding is a field of current studies (e.g. Khishfe, 2017) and should remain so, in order to eventually understand how such instruction impacts students' learning.

Overall, the results substantiate those of Papadouris und Constantinou (2014a) and extend them by providing quantitative data. At the same time, the results of our study provide evidence for the so-called "science-learning argument" (i.e. for NOS understanding potentially serving as a learning prerequisite for other science content), as it has been put forward by Driver and colleagues (1996). NOS can serve as a framework which 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 how this is in accordance with a realistic view of science and scientific knowledge. Given proper instruction, students could potentially be encouraged to use this epistemological understanding in the long term to also master the different non-epistemological aspects of energy (i.e. the properties that define and characterize the concept), like conservation or degradation, which they otherwise show difficulties with.

In order to find out whether epistemologically informed teaching is supportive for concepts other than energy as well, and which aspects of NOS are contributing to which aspects of conceptual understanding, further studies should examine other important concepts, identify their epistemological aspects and investigate how they can be taught to best effect. Furthermore, as the literature so far provides mixed results (see Michel et al., under review), more research is needed on the potential role of NOS for learning about disciplinary aspects of science concepts. Our study provides promising results as to the effect of integrated NOS instruction on both students' NOS and conceptual understanding about energy. Whether and how these results can be assigned to other concepts as well should be subject of further research.

7 DISKUSSION

Im Folgenden werden die zentralen Ergebnisse der vier Publikationen zusammengefasst und vor dem Hintergrund der in der Einleitung skizzierten Fragestellungen diskutiert. Auf Grundlage dieser Zusammenfassung werden abschließend Implikationen für die weitere naturwissenschaftsdidaktische Forschung wie auch für den Physikunterricht in der Praxis abgeleitet.

7.1 ZUSAMMENFASSUNG UND DISKUSSION DER STUDIENERGEBNISSE

Im Kern dieser Arbeit steht die theoretische und empirische Betrachtung des „lernpsychologischen Arguments“ („science learning argument“) für eine explizite Implementierung von NOS in den naturwissenschaftlichen Unterricht, welches Driver et al. (1996) formuliert haben. Driver et al. leiten das Argument aus dem damaligen Stand der theoretischen Diskussion und der verfügbaren empirischen Evidenz ab, so dass eine Neubewertung unter Berücksichtigung der Ergebnisse bildungswissenschaftlicher und naturwissenschaftsdidaktischer Forschung der letzten zwei Jahrzehnte sinnvoll erscheint. In einer umfassenden Synopse (Publikation 1) wurde dazu die ursprüngliche Formulierung und Begründung des lernpsychologischen Arguments noch einmal genau umrissen. Es zeigt sich, dass die grundlegenden Mechanismen, die Driver et al. hinter dem Zusammenhang zwischen NOS-Verständnis und konzeptuellem Verständnis annehmen, eher indirekter Natur sind. So werden Studien erwähnt, die eine positive Wirkung eines adäquaten NOS-Verständnisses auf Lernstrategien oder Motivation der Lernenden zeigen (welche sich wiederum auf das fachliche Lernen auswirken sollten), nicht jedoch direkt auf den Erwerb konzeptuellen Verständnisses. In der Literatur wird das lernpsychologische Argument jedoch auch oft in einem eher direkten Sinne formuliert. So beschreibt etwa Matthews (1997) die Bedeutung von NOS für ein Verständnis bestimmter naturwissenschaftlicher Themen. Um etwa die Kontroverse um Evolutionstheorie und Kreationismus, aber auch multikulturelle Aspekte und Genderfragen im Bereich der Naturwissenschaften umfassend verstehen zu können, sei ein Verständnis des Wesens naturwissenschaftlichen Wissens wichtige Voraussetzung (siehe auch McComas et al., 1998). Inwieweit eine Wirkung von NOS auf Lernprozesse in den Naturwissenschaften also indirekt, über andere lernförderliche Variablen, erfolgt, oder inwieweit sich auch direkte Mechanismen für einen

solchen Zusammenhang argumentieren und empirisch belegen lassen, wurde im Rahmen der genannten Synopse eingehend untersucht.

Für mögliche indirekte Mechanismen wurde dabei eine große Anzahl entsprechender Studien aus dem Bereich der Naturwissenschaftsdidaktik, der pädagogischen Psychologie oder anderer Disziplinen identifiziert. Im Bereich der affektiven und motivationalen Variablen konnte etwa ein positiver Zusammenhang zwischen NOS-Verständnis und Selbstkonzept (Baumert et al., 2000; Urhahne & Hopf, 2004), Selbstwirksamkeitserwartungen (Hacıeminoğlu, 2016; Parker, 2010; Tsai et al., 2011), Motivation (Alpaslan et al., 2016; Buehl & Alexander, 2005; Lin et al., 2013; Tsai, 1998), sowie Interesse in Naturwissenschaften (Baumert et al., 2000; Kruse, 2010; Urhahne & Hopf, 2004) gezeigt werden. Einige dieser Ergebnisse sind allerdings nicht ganz eindeutig, so finden sich bei genauerer Betrachtung für einzelne NOS-Aspekte zum Teil auch negative Wirkungen z.B. auf Selbstwirksamkeitserwartungen (Tsai et al., 2011) oder Lernmotivation (Ho & Liang, 2015), die weiteren Untersuchungsbedarf aufzeigen. Im Bereich kognitiver und metakognitiver Variablen zeigten sich z.B. Zusammenhänge zwischen NOS und Lernstrategien (Lee et al., 2016; Tsai, 1998; Urhahne & Hopf, 2004), Argumentationsstrategien (Archila, 2015; Bell & Linn, 2000; Khishfe, 2012a; 2012b; 2014) und Lernzielorientierung (Cavallo et al., 2003; Hacıeminoğlu, 2016). Insgesamt gibt es also eine breite empirische Grundlage für indirekte Mechanismen, durch die sich ein adäquates NOS-Verständnis auf Lernprozesse auswirken kann. Die genannten Mediatorvariablen dürften sich allerdings eher langfristig auf das konzeptuelle Verständnis der Schülerinnen und Schüler auswirken (Krapp, 2005; Vollmeyer, 2007), weshalb eine Thematisierung von NOS bereits in frühen Jahrgangsstufen sinnvoll sein könnte, um die genannten Variablen positiv zu beeinflussen.

Der Wissensstand zu möglichen direkten Mechanismen, also der direkten Beeinflussung von Lernprozessen zu bestimmten naturwissenschaftlichen Konzepten durch ein Verständnis bestimmter NOS-Aspekte, ist deutlich geringer. Eine systematische Literatursuche erbrachte nur acht Studien, die ein entsprechendes Studiendesign aufwiesen, um Rückschlüsse auf einen solchen Zusammenhang zuzulassen. Nicht alle davon waren dabei in einem Kontrollgruppendesign angelegt und nur eine der Studien (die in Publikation 2 vorgestellte erste empirische Studie in diesem Promotionsprojekt) ging der Fragestel-

lung nach einem direkten Zusammenhang zwischen NOS-Verständnis und konzeptuellem Verständnis explizit nach. Die betrachteten Studien weisen darüber hinaus ambivalente Ergebnisse aus. So fand Peters (2012) zum Beispiel eine positive Wirkung von NOS-orientierten metakognitiven Prompts auf Lernprozesse während einer Einheit zu Elektrizität und Magnetismus. Lin, Chan und van Aalst (2014) fanden ebenfalls Hinweise, dass ein Verständnis epistemischer Aspekte zu konzeptuellem Verständnis beitragen kann. Auf der anderen Seite zeigen die Ergebnisse von Kim und Irving (2010), Schwarz und White (2005), Irwin (2000) und Seker und Welsh (2006) keinen signifikanten Zusammenhang zwischen NOS und einem Verständniserwerb bzgl. naturwissenschaftlicher Konzepte in den Bereichen Genetik, Atommodellen sowie Kraft und Bewegung. Insgesamt besteht also nach wie vor eine gewisse Unklarheit über die Wirkung eines direkten Mechanismus.

Vor dem Hintergrund der Synopse erscheint eine erneute eingehende theoretische Betrachtung des direkten Mechanismus sinnvoll. Die Annahme einer direkten Wirkung des Verständnisses bestimmter NOS-Aspekte auf das Lernen disziplinären Fachwissens lässt sich – insbesondere vor dem Hintergrund der beschriebenen Studienergebnisse – kaum sinnvoll argumentieren. Die genannten indirekten Mechanismen mögen hier zwar einen Einfluss haben, eine direkter Wirkung bestimmter NOS-Aspekte auf das Verständnis fachlicher naturwissenschaftlicher Aspekte lässt sich aber wohl nur in Ausnahmefällen annehmen (die Hinweise auf eine Wirkung des NOS-Verständnisses auf den Lernzuwachs einzelner Schülerinnen und Schüler für den Aspekt der Energieentwertung in Publikation 2 könnten eine solche Ausnahme darstellen). Dies liegt allerdings auch daran, dass (wie in Abschnitt 1.3 beschrieben) Lernziele nach wie vor meist auf Fachinhalte bezogen werden und konzeptuelles Verständnis eher im Sinne der Vision I einer scientific literacy nach Roberts (2007) betrachtet wird. Erweitert man den Begriff konzeptuellen Verständnisses hingegen (im Sinne der in der Einleitung skizzierten Vision II) um epistemische und ontologische Aspekte – also ein Verständnis des Wesens eines naturwissenschaftlichen Konzepts und eine Wertschätzung seines Nutzens und seiner Erklärungsmächtigkeit – so lässt sich durchaus argumentieren, dass ein NOS-orientierter Zugang für die erfolgreiche Vermittlung eines solchen konzeptuellen Verständnisses notwendig und förderlich ist (Papadouris & Constantinou, 2011; 2017). Eine solche Einbeziehung epistemologischer Aspekte im naturwissenschaftlichen Unterricht fordern etwa Duschl

(1990), Driver et al. (1996) sowie Erduran, Bravo und Mamlok-Naaman (2007) seit längerer Zeit. Papadouris und Constantinou (2017) plädieren dafür, epistemologische Aspekte explizit als Teil des konzeptuellen Verständnisses in den Naturwissenschaften zu betrachten und entsprechend im Unterricht zu thematisieren. Voraussetzung hierfür ist, dass die entsprechenden Aspekte (1) einfach genug für eine altersgerechte Thematisierung, (2) ausreichend unumstritten sind, so dass eine ausführliche Auseinandersetzung mit wissenschaftsphilosophischen Diskursen nicht zwangsläufig erfolgen muss und (3) produktiv im Sinne einer Förderung fachlicher Lernvorgänge sind (Papadouris & Constantinou, 2017). Solche Aspekte können letztlich zusätzlich zu fachlichem Wissen eine Wertschätzung gegenüber naturwissenschaftlichen Konzepten bewirken und dazu führen, dass Schülerinnen und Schüler sich möglicherweise bei der Auseinandersetzung mit unbekanntem Phänomenen und Herausforderungen eher der entsprechenden Konzepte bedienen, auch wenn diese nicht zur Problemlösung vorgegeben sind (Papadouris & Constantinou, 2017). Betrachtet man nun diesen Teil konzeptuellen Verständnisses in den Naturwissenschaften unter den Gesichtspunkten des lernpsychologischen Arguments, so lassen sich viele Beispiele formulieren, in denen NOS-Aspekte mit epistemologischen Aspekten verknüpft sind und entsprechend ein Zugang über NOS bei der Verständnisbildung hilfreich sein kann. Die Synopse zeigt dabei einen breiten Forschungsbedarf bzgl. der Wirksamkeit entsprechender Unterrichtsangebote für die Entwicklung konzeptuellen Verständnisses – sowohl unmittelbar als auch langfristig.

In einer ersten empirischen Studie wurde hierzu im Rahmen dieses Promotionsprojekts untersucht, wie sich das NOS-Verständnis von Schülerinnen und Schülern auf die Entwicklung des konzeptuellen Verständnisses während einer Einheit zum Energiekonzept auswirkt (Publikation 2). 82 Schülerinnen und Schüler der sechsten und siebten Jahrgangsstufe von Schulen in Schleswig-Holstein nahmen dazu im Rahmen eines „Science Camps“ in den Sommerferien an einer Unterrichtseinheit zu Energie teil. Diese zielte vor allem auf die fachwissenschaftlichen Aspekte wie Energieformen, -transfer, -erhaltung und -entwertung; epistemologische Aspekte wurden nicht explizit thematisiert. Das Verständnis epistemologischer Aspekte des Energiekonzepts wurde als „nature of energy as a scientific concept“ (NETC) allerdings mit erhoben.

In der Auswertung zeigte sich für die erste Energieeinheit, die alle 82 Probanden durchliefen, kein signifikanter Zusammenhang des Lernerfolgs bzgl. fachwissenschaftlicher

Aspekte des Energiekonzepts mit dem NOS-Verständnis vor der Einheit. Für die 41 Schülerinnen und Schüler, die noch eine zweite Unterrichtseinheit erhielten, welche vor allem auf den Aspekt der Energieentwertung fokussierte, zeigte sich jedoch ein signifikanter Einfluss des NOS-Verständnisses auf den fachlichen Lernzuwachs. Energieentwertung gehört zu den Aspekten, bei denen Schülerinnen und Schüler im Allgemeinen mehr Verständnisschwierigkeiten zeigen, als etwa bei Energieformen oder -transfer (Neumann et al., 2013). Dieses Ergebnis könnte also darauf hinweisen, dass komplexere Aspekte naturwissenschaftlicher Konzepte bzw. Aspekte, die bei idealisierten theoretischen Betrachtungen ausgeklammert werden und erst in Bezug auf reale Bedingungen relevant werden, sich durch ein adäquates NOS-Verständnis besser an bestehendes Wissen anknüpfen lassen. Für NETC, also die epistemologischen Aspekte des Energiekonzepts, zeigten Schülerinnen und Schüler mit einem adäquateren NOS-Verständnis vor der Einheit signifikant höhere Verständnisszuwächse. Auch wenn also (wie in dieser Studie) eine Vermittlung epistemologischer Aspekte nur implizit erfolgt, scheint das NOS-Verständnis der Lernenden die Perspektive zu beeinflussen, aus welcher Lernende Wert und Nutzen des Energiekonzepts betrachten.

Vor dem Hintergrund der in Abschnitt 1.5 ausgeführten Forderung, NOS für einen authentischen Zugang mit fachlichen Inhalten zu verknüpfen (z.B. Clough, 2006) und auch, um eine positive Wirkung in Zusammenhang mit dem betrachteten Fachinhalt zu erzielen, erscheint es sinnvoll, NOS und fachliche Inhalte so miteinander zu verweben, dass auch die epistemische und ontologische Aspekte explizit angesprochen werden. In einer zweiten Studie wurde die Wirkung eines solchen integrierten Unterrichtsgangs untersucht. Hierzu wurden zunächst ontologische und epistemische Aspekte des betrachteten Fachinhalts (des Energiekonzepts) und damit in Zusammenhang stehende NOS-Aspekte identifiziert. Die Einführung der NOS-Aspekte erfolgte durch dekontextualisierte Aktivitäten, um die Schülerinnen und Schüler zunächst unabhängig von möglicherweise erschwerenden Fachinhalten an das für sie zumeist neue Thema NOS heranzuführen. Bei der darauffolgenden Erarbeitung fachwissenschaftlicher Aspekte werden diese dann allerdings durch Rückbezüge und entsprechende Gruppendiskussionen mit NOS-Aspekten verknüpft. So werden schließlich auch epistemologische Aspekte des Energiekonzepts herausgearbeitet. Einzelne entsprechende Aktivitäten wurden im Rahmen von Publikation 3 veröffentlicht.

In einer Interventionsstudie wurde die integrierte Unterrichtseinheit mit einer konventionellen Unterrichtseinheit verglichen, in welcher die fachwissenschaftlichen Aspekte im Vordergrund standen und weder NOS noch EAE explizit angesprochen wurden (Publikation 4). Die Stichprobe bestand dabei aus insgesamt 191 Schülerinnen und Schülern der Schleswig-Holsteinischen gymnasialen Oberstufe, welche im Rahmen zweitägiger Kursangebote zum Thema „Energie im Universum“ an je einer der beiden Unterrichtseinheiten teilnahmen. In beiden Kursprogrammen wurden fachwissenschaftliche Aspekte des Energiekonzepts (Formen, Übertragung, Erhaltung, Entwertung) angesprochen. Die in der integrierten Einheit explizit vermittelten EAE umfassten (1) ein Verständnis des theoretischen, abstrakten Wesens und der menschengemachten Natur des Energiekonzepts, (2) die disziplinübergreifende Bedeutung des Konzepts („crosscutting nature“) und (3) die Erklärungsmächtigkeit und Vorhersagekraft des Konzepts bei der Betrachtung naturwissenschaftlicher Phänomene (siehe Papadouris & Constantinou, 2011). NOS-Aspekte, die in diesem Zusammenhang thematisiert wurden, waren der Unterschied zwischen Beobachtungen und Schlussfolgerungen, die Vorläufigkeit naturwissenschaftlichen Wissens, Wesen und Gütekriterien naturwissenschaftlicher Theorien, sowie die Subjektivität und Kreativität von Wissenschaftlerinnen und Wissenschaftlern. Während NOS-Aspekte und EAE auch in der konventionellen Einheit (Kontrollgruppe) implizit enthalten waren, fand eine explizite Thematisierung nur im Rahmen der integrierten Einheit (Treatmentgruppe) statt.

In den Ergebnissen zeigte sich zwischen den Gruppen kein signifikanter Unterschied bzgl. des Fachwissens zum Energiekonzept. Auch bei einzelner Betrachtung der Energieaspekte (insbesondere mit Blick auf die in der ersten Studie gefundenen Hinweise auf eine mögliche Förderung des Verständnisses der Energieentwertung) ergaben sich keine relevanten Unterschiede. Bei Betrachtung der EAE zeigte sich allerdings ein signifikanter höherer Verständniszuwachs bei der Treatmentgruppe. Interessanterweise zeigte hier auch die Kontrollgruppe einen signifikanten Verständniszuwachs, der bei näherer Betrachtung vor allem auf ein stärkeres Bewusstsein des disziplinübergreifenden Nutzens („crosscutting nature“) des Energiekonzepts nach der Einheit zurückzuführen ist. Dieser Aspekt scheint also auch implizit durch die Anwendung des Energiekonzepts bei Bearbeitung verschiedener Aufgaben und Phänomene vermittelbar zu sein. Für das Verständnis der theoretischen Natur des Energiekonzepts und die Wertschätzung der Erklärungsmächtigkeit und Vorhersagekraft scheint auf Grundlage der Ergebnisse allerdings eine

explizite Thematisierung im Zusammenspiel mit NOS-Aspekten vonnöten, um diese Aspekte effizient zu vermitteln. Gleiches gilt für die Entwicklung des NOS-Verständnisses. Auch hier zeigte die Kontrollgruppe einen signifikanten Verständniszuwachs, welcher allerdings in der Treatmentgruppe deutlich größer ausfiel. Dieses Ergebnis entspricht dem früherer Untersuchungen, welche zeigen konnten, dass eine Vermittlung von NOS-Aspekten zwar auch implizit funktioniert, ein explizit-reflektiver Ansatz allerdings deutlich wirkungsvoller ist (z.B. Khishfe & Abd-El-Khalick, 2002). Für NOS wurde hierbei auch untersucht, ob die Schülerinnen und Schüler die NOS-Aspekte, die sie im Rahmen einer integrierten Einheit erarbeiten, in erster Linie mit dem Kontext der Einheit (in diesem Fall dem Energiekonzept) verknüpfen, oder ob sie ihr gewonnenes Verständnis auch auf andere Bereiche übertragen und so ein allgemeines, kontextübergreifendes NOS-Verständnis entwickeln. Vor der Intervention zeigen hier beide Gruppen ein eher inhomogenes, kontextabhängiges NOS-Verständnis. Während sich bei der Treatmentgruppe nach Durchlaufen der integrierten Einheit ein homogeneres Bild ergibt, bei dem sich keine signifikanten Unterschiede mehr zwischen den abgefragten Kontexten zeigen, bleibt das NOS-Verständnis der Kontrollgruppe auch nach der Einheit eher inhomogen.

Insgesamt lassen sich die im Rahmen dieses Promotionsprojekts erlangten Erkenntnisse unter drei verschiedenen Perspektiven diskutieren. Aus einer theoretischen Perspektive zeigt sich, dass die sinnvolle Begründung eines Zusammenhangs zwischen NOS-Verständnis und konzeptuellem Verständnis stark von der entsprechenden Konzeptualisierung abhängt. Wird konzeptuelles Verständnis vorwiegend in einem fachinhaltlichen Sinne betrachtet, bei welchem ein Verständnis grundlegender Wissens Elemente und Prozesse im Vordergrund steht, so lässt sich ein Einfluss von NOS auf diesbezügliche Lernprozesse schwer sinnvoll begründen (Publikation 1). Werden über das Verständnis fachwissenschaftlicher Aspekte hinaus allerdings auch epistemologische Aspekte naturwissenschaftlicher Konzepte als Bestandteil konzeptuellen Verständnisses betrachtet (siehe Papadouris & Constantinou, 2017), kann ein NOS-orientierter Unterricht neue Perspektiven auf naturwissenschaftliche Konzepte wie Energie eröffnen, die sonst nur schwer zugänglich sind (Publikationen 1, 3, 4).

Betrachtet man die Ergebnisse aus empirischer Sicht, so zeigen sich ebenfalls kaum Hinweise auf einen direkten Zusammenhang zwischen NOS und fachwissenschaftlichen Aspekten. Es zeigt sich allerdings ein Zusammenhang zwischen NOS-Verständnis und

Lernzuwachs bzgl. epistemologischer Aspekte des Energiekonzepts. Ist dieser Zusammenhang in den Ergebnissen der ersten Studie noch rein korrelativ (Publikation 2), lässt die zweite, quasi-experimentelle Studie deutlichere Rückschlüsse auf die Wirksamkeit einer entsprechenden integrierten Unterrichtseinheit zu. Eine explizite Thematisierung der epistemologischen Aspekte und die Verknüpfung mit relevanten NOS-Aspekten scheint ein Verständnis beider Bereiche wirksam zu fördern (Publikation 4). So zeigen sich bei entsprechender Instruktion vor allem ein besseres Verständnis der theoretischen Natur, sowie eine höhere Wertschätzung der Erklärungsmächtigkeit und Vorhersagekraft des Energiekonzepts.

Aus unterrichtspraktischer Sicht heraus legt die Arbeit dar, dass ein unterrichtlicher Zugang zu epistemologischen Aspekten naturwissenschaftlicher Konzepte über eine Vermittlung von NOS-Aspekten und eine nachfolgende Verknüpfung mit fachlichen Inhalten erfolgen kann (Publikation 3). Auch wenn sich einzelne epistemologische Aspekte (wie auch einzelne NOS-Aspekte) offenbar implizit vermitteln lassen, scheint ein explizit-reflektiver Ansatz hierfür deutlich effizienter.

7.2 IMPLIKATIONEN FÜR DIE FACHDIDAKTISCHE FORSCHUNG

Auf Grundlage der hier dargestellten Ergebnisse scheint eine weitere Untersuchung und Diskussion des lernpsychologischen Arguments für eine Implementierung von NOS im Unterricht lohnenswert. Eine zentrale Implikation dieser Arbeit ist dabei die Bedeutung der Definition konzeptuellen Verständnisses für den untersuchten Zusammenhang. Stellt man über die zu leistende fachliche Ausbildung und Wissenschaftspropädeutik hinaus die Befähigung zur Teilnahme an gesellschaftlichen Diskussions- und Entscheidungsprozessen in den Mittelpunkt naturwissenschaftlicher Bildung (entsprechend der Vision II einer scientific literacy nach Roberts, 2007), so rücken auch epistemologische Aspekte naturwissenschaftlicher Konzepte als wichtiger Bestandteil konzeptuellen Verständnisses in den Mittelpunkt. Für das Energiekonzept konnte die Wirkung eines entsprechenden explizit-reflektiven Zugangs im Rahmen einer integrierten Unterrichtseinheit gezeigt werden. Offen bleibt jedoch, ob ein solcher Zugang auch für andere Konzepte und Inhalte zielführend ist. Papadouris und Constantinou (2017) beschreiben allgemeingültige Kriterien für die Auswahl unterrichtsrelevanter epistemologischer Aspekte und formulieren

neben dem Energiekonzept auch für Magnetismus entsprechende Vorschläge. Im Rahmen dieser Arbeit wurde ein möglicher Zusammenhang zwischen NOS-Verständnis und Fachlernen in Physik im Kontext des Energiekonzepts untersucht. Die Befunde lassen sich damit nicht ohne Weiteres auf andere naturwissenschaftliche Konzepte und Fachinhalte übertragen, insbesondere da die untersuchten Wirkungen auf epistemologische Aspekte sich sehr spezifisch auf den Energiebegriff beziehen. Soll die Vermittlung im Unterricht allgemein erfolgen, so ist eine Identifikation entsprechend bedeutender epistemologischer Aspekte auch für andere Konzepte und Inhalte notwendig. Auch für diese sollte dann untersucht werden, ob sich deren Vermittlung über einen NOS-orientierten, integrierten Unterrichtsansatz fördern lässt.

Neben der theoretischen Argumentation für eine Vermittlung epistemologischer Inhalte im Unterricht, wie sie etwa durch Duschl (1990), Driver et al. (1996), Erduran, Bravo und Mamlok-Naaman (2007) sowie Papadouris und Constantinou (2017) geführt wird, ließe sich diese auch empirisch untersuchen. So könnte etwa die Wirkung eines Verständnisses epistemologischer Aspekte bestimmter Konzepte auf die Herangehensweise der Lernenden bei der Konfrontation mit unbekanntem naturwissenschaftlichen Herausforderungen betrachtet werden. Wie im Diskussionsteil ausgeführt lässt sich die Vermutung formulieren, dass eine höhere Wertschätzung des fächerübergreifenden Nutzens eines Konzepts dazu führen könnte, dass auf dieses bereitwilliger bei der Bearbeitung von Problemen zurückgegriffen wird, zu deren Lösung keine Vorgaben bzgl. der zu verwendenden Konzepte und Inhalte gemacht werden (Papadouris & Constantinou, 2017). Ließe sich ein solcher Zusammenhang auch empirisch stützen, hätte dies weitreichende Implikationen auf die Bedeutung epistemologischer Aspekte im Sinne einer scientific literacy. Gleiches gilt für die mögliche Wirkung eines Verständnisses von NOS bzw. epistemologischer Aspekte naturwissenschaftlicher Konzepte auf die Fähigkeit, Beziehungen zwischen Inhalten verschiedener naturwissenschaftlicher Disziplinen herzustellen und so ein integriertes Naturwissenschaftsverständnis zu fördern. Schließlich wäre auch zu untersuchen, ob ein Verständnis von NOS bzw. epistemologischer Aspekte eine positive Wirkung auf das Interesse von Schülerinnen und Schülern an Physik hat und somit dem vielbeschriebenen Interessensabfall während der Schulzeit (siehe z.B. Duit, 1997) entgegenwirken kann. Ein solcher Effekt könnte sich letztlich auch auf die Kurswahlen in der Oberstufe,

die spätere Studienwahl, aber auch auf die Bereitschaft zur Beteiligung an gesellschaftlichen Entscheidungsprozessen mit naturwissenschaftlichem Bezug auswirken. Auch zu solchen Wirkungen stehen belastbare Studienergebnisse allerdings noch aus.

Neben solchen direkten Wirkungen lassen sich auch indirekte Mechanismen für einen Zusammenhang zwischen NOS und fachlichen Lernprozessen weiter untersuchen. Zwar lassen sich aus der vorhandenen Forschungsliteratur viele potentielle Mechanismen ableiten (Abschnitt 3.4), der Großteil der hierfür herangezogenen empirischen Belege ist allerdings korrelativer Natur und lässt keine kausalen Schlüsse zu. Für die Untermauerung einer angenommenen Wirkung von NOS-Verständnis auf lernprozessrelevante Variablen und Fähigkeiten (und damit mittelbar auf den Erwerb konzeptuellen Verständnisses) sind Langzeitstudien notwendig, die die Wirkung von NOS-Instruktion und des Aufbaus eines entsprechenden Verständnisses über längere Zeit beobachten. Solche langfristigen Untersuchungen könnten auch Aufschluss zu der Frage geben, ob NOS an einzelnen Stellen des Curriculums konzentriert thematisiert werden sollte, oder ob eine kontinuierliche Vermittlung im Sinne eines Spiralcurriculums zielführend ist.

7.3 IMPLIKATIONEN FÜR DEN UNTERRICHT

Für die Praxis des Physikunterrichts ergeben sich verschiedene Implikationen aus den Befunden dieser Arbeit. Zunächst ergibt sich vor allem im deutschsprachigen Raum die Frage, inwieweit NOS, aber auch epistemologische Aspekte naturwissenschaftlicher Konzepte, im Physikunterricht vermittelt werden sollten. Für ein integriertes Verständnis der Naturwissenschaften und insbesondere im Sinne einer erweiterten Vision II einer scientific literacy (Roberts, 2007) lässt sich argumentieren, dass Aspekte wie die Wertschätzung der Erklärungsmächtigkeit und des Nutzens naturwissenschaftlicher Theorien und Konzepte wichtige Komponenten sind, die auch im Zusammenhang mit naturwissenschaftlichen Fachinhalten erarbeitet werden sollten (Driver et al., 1996; Duschl, 1990; Erduran et al., 2007; Papadouris & Constantinou, 2017). Eine stärkere Berücksichtigung in Standards und Fachanforderungen wäre entsprechend empfehlenswert. In der individuellen Ausgestaltung des Unterrichts bietet eine Auseinandersetzung mit solchen epistemologischen Aspekten die Chance, Schülerinnen und Schülern neue Perspektiven auf

naturwissenschaftliche Inhalte zu eröffnen und sie auf Wesen und Werte der Naturwissenschaften aufmerksam zu machen. So könnte nicht zuletzt auch dem sinkenden Interesse an Physik bei Schülerinnen und Schülern entgegengewirkt werden (Duit, 1997).

Eine Verknüpfung von NOS mit Fachunterricht ist neben Energie auch für andere Konzepte denkbar (z.B. Magnetismus, Papadouris & Constantinou, 2017) und kann nach einem ähnlichen Schema erfolgen, wie im Rahmen dieser Arbeit dargelegt (Publikation 3). Die Vermittlung von NOS-Aspekten, wie auch von epistemologischen Aspekten naturwissenschaftlicher Konzepte sollte dabei explizit erfolgen, damit sie wirkungsvoll ist (siehe auch Khishfe & Abd-El-Khalick, 2002; Papadouris & Constantinou, 2017). Die thematisierten epistemologischen Aspekte sollten einfach genug für eine altersgerechte Thematisierung, ausreichend unumstritten und produktiv im Sinne einer Förderung fachlicher Lernvorgänge sein (Papadouris & Constantinou, 2017). NOS-Aspekte, fachwissenschaftliche sowie epistemologische Aspekte naturwissenschaftlicher Konzepte können unabhängig voneinander eingeführt, sollten im weiteren Verlauf aber eng miteinander verknüpft und immer wieder aufeinander bezogen werden. Ziel ist es dabei, langfristig nachhaltige Lernprozesse zu befördern, die schließlich zu einem umfassenden und integrierten Verständnis der Naturwissenschaften und ihrer zentralen Konzepte, sowie zu einer Befähigung zur Auseinandersetzung mit gesellschaftlich relevanten Situationen und Fragestellungen führen.

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ANHANG PUBLIKATION 2

Table 10: Reliability for the used assessment instruments.

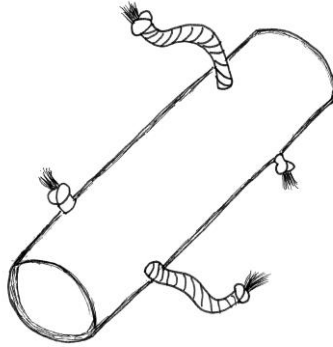
Variable	n (Items)	Cronbach's alpha	
		Pretest	Posttest
Content knowledge on energy (CKE)	30	.75	.78
Nature of science understanding (NOS)	22	.67	.78
Understanding of nature of energy as a theoretical concept (NETC)	10	.64	.73
Motivation	7	.64	.73
Interest in physics	5	.70	-
Self-concept in physics	4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

Table 11: descriptive statistics for total sample.

Variable	n	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

ANHANG PUBLIKATION 3

Die *Mystery-Tube*



1. Seht euch die *Mystery Tube* genauer an. Probiert aus, was man damit machen kann.
2. Beschreibt möglichst genau, was ihr bei der *Mystery Tube* beobachten könnt!

Arbeitsblatt 1: Die Mystery Tube

Die Bewegungstheorie des Aristoteles

Lest den folgenden Text:

„Der Versuch, die Bewegungen von Gegenständen, Flüssigkeiten und Gasen zu erklären, hat in der Geschichte der Wissenschaft immer viel Aufmerksamkeit erhalten. Eine Theorie für die Bewegung lautet folgendermaßen:

Alle irdischen Objekte bestehen aus den vier Elementen: Erde, Wasser, Luft und Feuer. Einige Objekte bestehen nur aus einem dieser Elemente, andere hingegen enthalten mehrere Elemente in bestimmten Mengen. Jedes dieser Elemente hat einen *natürlichen Ort*: Erde hat ihren natürlichen Ort im Zentrum des Planeten, der natürliche Ort von Wasser ist über der Erde, der von Luft darüber und Feuer hat seinen natürlichen Ort schließlich ganz oben über der Luft.

Ein Objekt, das hauptsächlich aus Erde besteht (ein Stein zum Beispiel) bewegt sich nach unten (fällt herunter), bis es sich an seinem natürlichen Ort befindet. Etwas, das hauptsächlich aus Luft besteht (zum Beispiel Dampf), bewegt sich aufwärts. So lassen sich viele Phänomene erklären, zum Beispiel ein ausbrechender Vulkan: Wasser und Feuer, die in der Erde eingeschlossen ist, können entweichen und fliegen dabei hoch in die Luft.“

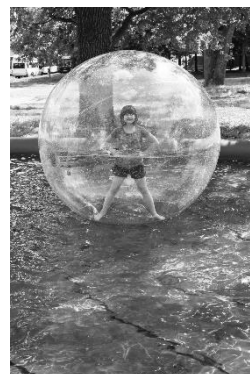
1. Schaut euch die Freizeitparkattraktion auf eurem Foto an und überlegt, welches Element bzw. welche Elemente ihr eurer Attraktion laut der Bewegungstheorie des Aristoteles zuordnen würdet.
2. Findet eine Erklärung für die Funktionsweise eurer Attraktion mit Hilfe der beschriebenen Bewegungstheorie.
3. Präsentiert eure Ergebnisse auf einem Poster.



Free Fall Tower



Achterbahn



Water Walking Ball



Feuerspucker

Die Bewegungstheorie des Aristoteles (II)

1. Schaut euch wieder die Freizeitparkattraktion auf eurem Foto an!
2. Überlegt, welches Element bzw. welche Elemente (Erde, Wasser, Feuer, Luft) ihr dieser Attraktion zuordnen könnt.
3. Findet eine Erklärung für die Funktionsweise eurer Attraktion mit Hilfe der Bewegungstheorie des Aristoteles.



Looping



Schiffsschaukel



Bungee-Trampolin

Arbeitsblatt 2b: Die Bewegungstheorie des Aristoteles (II)

ANHANG PUBLIKATION 4

Table 12: Descriptive statistics for both groups.

Variable	Treatment group					Control group				
	n	min	max	mean	SD	n	min	max	mean	SD
Motivation pretest	94	2,57	5,00	4,07	0,54	97	2,00	5,00	4,05	0,57
CKE pretest	94	0,50	23,00	10,02	5,43	97	0,50	26,50	10,53	5,05
CKE posttest	94	2,00	29,00	15,43	5,56	97	3,50	28,50	15,93	5,90
EAE pretest	94	0,00	10,00	3,84	2,52	97	0,00	11,00	4,01	2,49
EAE posttest	94	0,50	15,00	6,55	2,96	97	1,00	12,00	5,23	2,57
NOS pretest	94	3,08	6,54	4,53	0,71	97	2,77	5,92	4,51	0,77
NOS posttest	94	4,15	7,00	5,69	0,70	97	3,08	6,85	4,89	0,82
CNOS-energy pretest	94	1,71	7,00	3,85	1,16	97	1,57	6,57	3,90	1,15
CNOS-energy posttest	94	3,00	7,00	5,34	1,10	97	1,71	7,00	4,21	1,12
CNOS-evolution pretest	94	1,71	7,00	3,94	1,15	97	1,57	6,71	3,93	1,18
CNOS-evolution posttest	94	2,71	7,00	5,19	1,05	97	1,43	7,00	4,33	1,19
CNOS-atomic mod. pretest	94	2,29	7,00	4,31	0,99	97	1,71	7,00	4,24	1,14
CNOS-atomic mod. posttest	94	3,14	7,00	5,38	1,11	97	2,14	7,00	4,49	1,07

EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, dass ich die vorliegende Dissertation – abgesehen von der Beratung durch meine Betreuer*innen – nach Inhalt und Form selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Die Arbeit ist unter Einhaltung der Regeln guter wissenschaftlicher Praxis der Deutschen Forschungsgemeinschaft entstanden. Sie wurde weder im Ganzen noch in Teilen an einer anderen Stelle im Rahmen eines Promotionsverfahrens vorgelegt. Teile dieser Arbeit wurden bereits in Form von Zeitschriftenartikeln publiziert bzw. sind zur Publikation eingereicht.

Kiel, den

Hanno Michel