

Nature of Science and Science Content Learning: Can NOS Instruction Help Students Develop a Better Understanding of the Energy Concept?

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Abstract

Besides viewing knowledge about the nature of science (NOS) as important for its own value with respect to scientific literacy, an adequate understanding of NOS is expected to improve science content learning by fostering the ability to interrelate scientific contents and, thus, coherently acquire scientific content knowledge (Driver et al., 1996). However, there is a lack of systematic investigations, which clarify the relations between NOS instruction and learning achievement in science (Lederman, 2007; Peters, 2012). This paper presents the theoretical framework, design and methods of a respective study to empirically investigate whether NOS instruction is able to foster students' acquisition of a proper understanding of the physics concept of energy. Three intervention groups are to receive different types of instruction. One group is to receive decontextualized NOS instruction, followed by a unit on energy, while a second group only receives instruction on energy, without explicitly addressing NOS aspects. A third group is to receive integrated NOS instruction, where aspects of both NOS and energy are meaningfully interwoven in order to support each other. Pre- and post-tests assessing NOS and energy understanding, as well as student interviews are used to investigate if and how students use their NOS understanding to approach science content.

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Introduction

Nature of science (NOS) has long time been promoted an important content of science education (Lederman, 2007) and has consequently been included in multiple standard documents worldwide (e.g. AAAS, 1993; National Research Council, 1996; NGSS Lead States, 2013; McComas & Olson, 1998). Besides viewing NOS knowledge as important for its own value with respect to scientific literacy, scholars also mention the so-called “science learning argument” for teaching NOS in school: That is, an adequate understanding of NOS is expected to improve science content learning by fostering the ability to interrelate scientific content and, thus, coherently acquire scientific content knowledge (Driver et al., 1996). However, “this assumption [...] has yet to be systematically tested” (Lederman, 2007, p. 871), a statement that is still valid by today (Peters, 2012). The present study aims to address this lack of systematic investigations and to clarify the relation between NOS instruction and learning achievement in physics, specifically focusing on students’ understanding of the energy concept.

Theoretical Background

Nature of Science, Epistemological Beliefs and Science Content Learning

Education and science education literature provides multiple factors that play a role in students’ acquisition of science content knowledge, including their intrinsic motivation, interest, and self-concept in science (Cavallo et al., 2003; Deci & Ryan, 1985; Leibham et al., 2013), as well as their epistemological beliefs (Cavallo et al., 2003; Tsai, 1998). Epistemological beliefs (EB) and NOS are closely related, though Hogan (2000) recommends to clearly distinguish between them from a science education research perspective. EB refer to „individual representations about knowledge and knowing“ (Mason & Bromme, 2010, p. 1), whereas NOS refers to “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). There obviously is a particular overlap between NOS and EB (Hogan, 2000; Lederman, 2007), hence, taking a closer look on the relationship between NOS and science content learning includes reviewing literature on the facilitating role of students’ EB.

The influence of EB on science content learning is well-investigated (Yang & Tsai, 2012). Several empirical studies revealed a positive impact of sophisticated EB on students’ learning strategies (Tsai, 1998), self-set learning goals (Cavallo et al., 2003), reasoning skills and argumentation (Bell & Linn, 2000), and metacognitive abilities (Tsai, 1998). Overall, these

effects are highest for those aspects of EB that show significant overlap with aspects of NOS. Concerning NOS, positive effects of adequate NOS views on students' knowledge integration (Songer & Linn, 1991), problem-solving strategies (Lin & Chiu, 2004), and scientific reasoning (Sadler et al., 2004) have been reported. All of these characteristics and skills are considered to foster an integrated understanding of science content knowledge. As a consequence, one may assume that NOS understanding may foster science content learning as well.

Effective Teaching of Nature of Science

Although NOS understanding seems to be an important factor influencing learning processes, studies show that students and teachers of all ages continue to hold inadequate and naïve views of NOS (Abd-El-Khalick & Lederman, 2000; Dogan & Abd-El-Khalick, 2008; Höttecke, 2004; Ibrahim et al., 2009; Khishfe & Abd-El-Khalick, 2002). An implicit approach of teaching NOS, in which adequate views of scientific knowledge and practices are to be achieved by having students conduct experiments without reflecting on their actions has only little effect on students' NOS views (Khishfe & Abd-El-Khalick, 2002). Furthermore, this approach holds the risk of students developing two parallel views of science and scientific inquiry – one that they derive from their everyday experiences and the media, and a second one based on and connected only to their in-school experiences, as students often do not regard their own actions as being authentically “scientific” (Clough, 2006; Solomon, 1991). In order to trigger an inner conflict in students' ways of thinking and to have them consciously reconsider their own NOS understanding, an explicit-reflective approach is necessary, which is designed to direct students' attention towards important NOS aspects and to discuss them critically (Abd-El-Khalick & Lederman, 2000; Akerson et al., 2000; Bell et al., 2000; Clough, 1997, Clough, 2006; Khishfe & Abd-El-Khalick, 2002; Lederman, 2007). This can be achieved by explicitly teaching NOS aspects to students prior to their own scientific approaches, as well as subsequently reflecting and discussing, how their actions compare to those of “real-life” scientists (Akerson et al., 2010).

A typical method for explicitly addressing NOS are generic NOS activities (Lederman & Abd-El-Khalick, 1998), which illustrate certain NOS aspects with no or very little reference to other science content. Such decontextualized activities, however, may be regarded as non-authentic by students, since they do not resemble their perception of “real” science. This can lead to the problem of two parallel views of science, as depicted above (Clough, 2006). In addition, teachers may view NOS activities as “add-ons”, which take time from addressing

science content considered more important (Abd-El-Khalick et al., 1998; Lakin & Wellington, 1994). In order to confront this concern and to create an authentic access to NOS, NOS should best be taught contextualized (Brickhouse et al., 2000; Clough, 2006; Driver et al., 1996; Schwartz & Crawford, 2004). If NOS and science content aspects are meaningfully interwoven, learners have the chance to establish relationships between their own experiences and scientific practices authentically. Furthermore, teachers are less likely to dismiss NOS implementation as being too time-consuming.

For introducing NOS aspects to students in a contextualized instructional setting, generic NOS activities can nevertheless be worthwhile, when somehow connected to science content. This connection does not necessarily have to be made immediately, but can be established when NOS aspects and the correspondent content have been introduced separately, thus avoiding the risk of sidetracking students by introducing NOS and science content aspects at the same time (Leach et al., 2003). Then, contextualized NOS instruction can be realized via open or guided inquiry, class discussion, hands-on activities, or by reviewing historical case studies or experiments (Akerson et al., 2010; Clough, 2006). The role of the teacher in such an instructional setting would be moderating discussions on similarities and differences between scientific actions in class and historical or modern approaches, as well as generic NOS activities, respectively (Clough, 2006).

Besides the above approaches and apart from the context of evolution, however, examples of instruction that embed NOS within science subject matter are relatively few (Schwartz, 2013), as are studies investigating the effect of such contextualized NOS instruction on students' acquisition of the correspondent science content. For example, Peters (2012) found that NOS-oriented metacognitive prompts can facilitate the acquisition of science content when taught in the context of electricity and magnetism. On the other hand, the picture on the effect of EB and NOS understanding on learning achievement in general is not completely clear. For instance, Cavallo et al. (2003) found a direct effect of more sophisticated EB on learning only for biology, but not for physics concepts. In contrast, Schwartz (2013) did not find any interrelation between students' conceptions of NOS and conceptions of biology at all.

In summary, the relations between NOS instruction, NOS understanding, and science content learning are inconclusive. Additional applied research is needed to find out if and how learning processes can practically be supported by fostering students' NOS understanding. Particularly, the role of NOS instruction – decontextualized or contextualized – and subsequent

gain in NOS understanding with respect to science content learning appears to be unclear. Most studies measure students' EB or NOS understanding once as an outcome variable, as NOS understanding is regarded an important learning goal for its own value, or as a control variable. However, to investigate the impact of a NOS-informed curriculum on science learning processes, it is important to further address possible changes in NOS understanding during the intervention, and to examine, how students use such understanding to approach science content.

Purpose of the study

Considering the above literature, this study therefore addresses the following research question: "How does NOS-oriented instruction influence students' physics content learning and NOS understanding?" Here, NOS-oriented instruction means either decontextualized instruction about NOS, without addressing science content, or contextualized NOS-instruction, where aspects of NOS and of science content are meaningfully interwoven. The following hypotheses are proposed: (1) NOS-instruction prior to an instructional unit about science content positively influences science content learning. (2) Contextualized NOS instruction, where NOS aspects and science content aspects are supporting each other in a meaningful way throughout the instructional unit, better fosters both NOS and content knowledge than instruction on science content only or a combination of science content instruction and decontextualized NOS instruction.

Method

Study Design

To approach the above research question an intervention study with a control group design is conducted. Three intervention groups (Fig. 1), consisting of approximately 40 seventh grade students each, are to receive different types of instruction, all addressing the physics concept of energy. Hypothesis 1 is to be tested by comparing groups 1 and 2, both receiving the same three lesson unit on energy, with group 1 receiving three lessons of generic instruction on NOS in advance. To test hypothesis 2 a third group is to receive six lessons of explicit-reflective contextualized NOS instruction (Clough, 2006), embedded in an energy context. In this group, aspects of both concepts, NOS and energy, are to be meaningfully interwoven in order to support each other in terms of student understanding. In order to allow for comparison with group three, group two is to receive three additional lessons on energy after an interim assessment focusing on content knowledge. The lessons are planned to take 90 minutes each

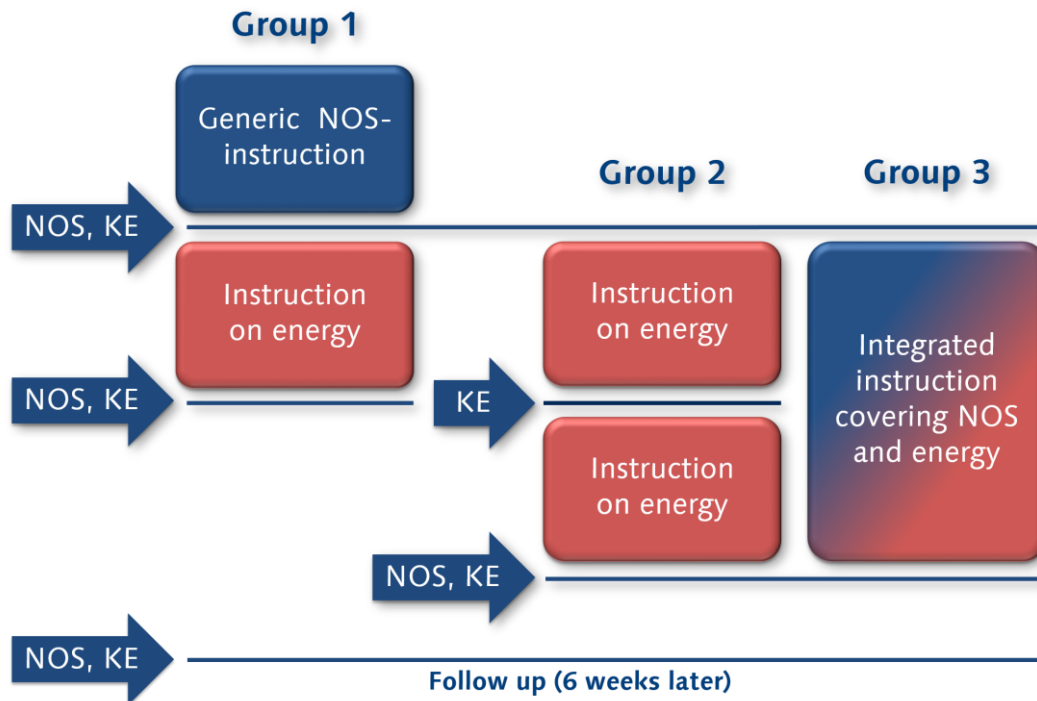


Fig. 1: Study design with three intervention groups. Arrows indicate when tests are administered (NOS = nature of science, KE = knowledge about energy).

and are situated in a laboratory out-of-school setting. All interventions are to cover two to three full days in total, including time for warm-up activities and assessment. Participating students are randomly assigned to one of the groups and all groups are taught by the same person.

Intervention Design

The two groups receiving NOS-oriented instruction represent the two sides of the decontextualized/contextualized continuum according to Clough (2006). In group 1, NOS instruction is realized by performing generic NOS activities (Lederman & Abd-El-Khalick, 1998) and subsequently discussing them, without connecting them to other science content. Thus, students can concentrate on critically questioning and evolving their own views about science, which can be a challenging task for its own, without being distracted by potentially complex scientific content. On the other hand, group 3 receives a more diverse approach to the same NOS aspects, which is closely linked to the context of energy. Papadouris and Constantinou (2011; 2014) provide a philosophically informed approach towards energy, including generic activities which are linked to content-related experiments, as well as epistemic discourses addressing and reflecting important NOS aspects. In the integrated NOS unit, these activities are supported by studying historical case studies. NOS aspects emphasized

in both NOS-oriented units are (1) the difference between observation and inference, and (2) the nature and tentativeness of scientific theories, as these aspects are assumed most important for a proper understanding of the physics energy concept. The correspondent learning goal is for students to view energy as a theoretical framework that has been invented, elaborated and refined in scientific history in order to explain a wide variety of phenomena.

The instructional units on energy cover the same aspects and follow the same learning goals for all three groups. Typically, four aspects of energy are considered important for instructional implementation, which are often taught in this sequence: (1) Energy forms and sources, (2) energy transfer and transformation, (3) energy degradation, and (4) energy conservation (Duit, 2013; Neumann et al., 2013). In the instructional unit, experiments and activities are put in the context of exploring a theme park. Rollercoasters, bungee jumps and bumper cars are used to introduce and elaborate the forms of kinetic, potential and elastic energy as well as transformation processes between the mentioned forms. Several of the activities and experiments have been taken from the IQWST curriculum, providing a hands-on approach towards energy and its conservation (Fortus et al., 2012). Group 1, which has received generic NOS instruction in advance, and group 2 receive the same three lesson energy unit that does not include explicit teaching of NOS. Group 2 is then receiving an additional three lesson unit on energy, including activities that repeat and consolidate the content taught before. For group 3, NOS aspects are distributed throughout the energy-related lessons (e.g. Constantinou & Papadouris, 2012; Papadouris & Constantinou, 2011; Papadouris & Constantinou, 2014).

In summary, the interventions share the same learning goals and contents regarding energy, as well as similar teaching methods, and differ only in the way they address NOS aspects and in the time-on-task they provide for explicitly addressing energy aspects.

Data Collection

Before and after the intervention units, students are administered questionnaires on their NOS understanding and on their understanding of the energy concept. Students' NOS understanding is assessed by using multiple choice items (NOSSI; Neumann, 2011) as well as open ended items (VNOS-C; Abd-El-Khalick, 1998) before and after the units to examine how their prior NOS knowledge, as well as their gain in NOS understanding during the intervention, effects their acquisition of science content knowledge. Assessment on energy understanding is also consisting of multiple choice as well as open ended items, focusing on declarative and integrated knowledge about energy and about the nature of energy as a scientific concept. Both

the tests on NOS and on energy understanding are to cover not only the aspects emphasized in the instructional units, but additional aspects as well, in order to investigate whether students develop deeper understandings of aspects only addressed implicitly additional to the aspects explicitly discussed in the interventions. Furthermore, the post-test will include the evaluation of students' motivation, given that several sources assume or showed effects of students' NOS views and EB on this variable (Clough, 2011; Driver et al., 1996; Urhahne & Hopf, 2004). Students' cognitive abilities and science, math, and German grades serve as control variables. Six weeks after the intervention there is to be a follow-up assessment covering NOS and energy understanding to examine potential differences in long-term effects.

In addition to the questionnaires, some of the participating students in the two groups receiving NOS-oriented instruction are to be interviewed. This shall allow for deeper investigation of when and how students use their NOS understanding to approach science content.

Conclusion

Overall, the study aims to shed more light on the interactions between NOS instruction and science content learning. Thus, the study contributes to the overall line of study if and how NOS should be addressed in science instruction in order to improve students' learning processes. Results aligned with the investigated hypotheses may not only provide insights into the learning of NOS and science content knowledge, but may also inform teachers about the importance of fostering NOS understanding in school in order to promote student learning – a research goal which is of special importance in Germany, where NOS is not explicitly part of curricula and educational standards yet.

References

- Abd-El-Khalick, F. S. (1998). *The influence of history of science courses on students' conceptions of nature of science* (Unpublished doctoral dissertation). Oregon State University, Corvallis.
- Abd-El-Khalick, F. S., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, 82, 417–436.
- Abd-El-Khalick, F. S., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: a critical review of the literature. *International Journal of Science Education*, 22(7), 665–701
- Akerson, V. L., Abd-El-Khalick, F. S., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching*, 37(4), 295–317.
- Akerson, V. L., Weiland, I., Pongsanon, K., & Nargund, V. (2010). Evidence-based strategies for teaching nature of science to young children. *Journal of Kirsehir Education Faculty*, 11(4), 61–78.

- Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: designing for learning from the web with KIE. *International Journal of Science Education*, 22(8), 797–817
- Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. S. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. *Journal of Research in Science Teaching*, 37(6), 563–581.
- Brickhouse, N. W., Dagher, Z. R., Letts, W. J., & Shipman, H. (2000). Diversity of Students' Views about Evidence, Theory, and the Interface between Science and Religion in an Astronomy Course. *Journal of Research in Science Teaching*, 37(4), 340–362.
- Cavallo, A. M., Rozman, M., Blickenstaff, J., & Walker, N. (2003). Learning, reasoning, motivation, and epistemological beliefs. *Journal of College Science Teaching*, 33, 18–23.
- Clough, M. P. (1997). Strategies and Activities for Initiating and Maintaining Pressure on Students' Naive Views Concerning the Nature of Science. *Interchange*, 28(2-3), 191–204.
- Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education*, 15(5), 463–494
- Clough, M. P. (2011). The Story Behind the Science: Bringing Science and Scientists to Life in Post-Secondary Science Education. *Science & Education*, 20(7-8), 701–717
- Constantinou, C., & Papadouris, N. (2012). Teaching and learning about energy in middle school: an argument for an epistemic approach. *Studies in Science Education*, 48(2), 161–186
- Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior. Perspectives in social psychology*. New York: Plenum.
- Dogan, N., & Abd-El-Khalick, F. S. (2008). Turkish grade 10 students' and science teachers' conceptions of nature of science: A national study. *Journal of Research in Science Teaching*, 45(10), 1083–1112
- Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Buckingham: Open Univ. Press.
- Duit, R. (2013). *Teaching and Learning the Physics Energy Concept*. Retrieved from <http://esummit-msu.net/content/teaching-and-learning-physics-energy-concept>
- Fortus, D., Abdel-Kareem, H., Chen, J., Forsyth, B., Grueber, D. J., Nordine, J., & Weizman, A. (2012). Why do some things stop while others keep going? In J. S. Krajcik, B. J. Reiser, D. Fortus, & L. M. Sutherland (Eds.), *Investigating and questioning our world through science and technology (IQWST)*. New York: Sangari Science.
- Hogan, K. (2000). Exploring a process view of students' knowledge about the nature of science. *Science Education*, 84, 51–70.
- Höttecke, D. (2004). Schülervorstellungen über die "Natur der Naturwissenschaften. In C. Höhle, D. Höttecke, & E. Kircher (Eds.), *Lehren und Lernen über die Natur der Naturwissenschaften* (pp. 264–277). Baltmannsweiler: Schneider-Verl. Hohengehren.
- Ibrahim, B., Buffler, A., & Lubben, F. (2009). Profiles of freshman physics students' views on the nature of science. *Journal of Research in Science Teaching*, 46(3), 248–264
- Khishfe, R., & Abd-El-Khalick, F. S. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, 39(7), 551–578
- Lakin, S., & Wellington, J. (1994). Who will teach the 'nature of science'?: teachers' views of science and their implications for science education. *International Journal of Science Education*, 16(2), 175–190
- Leach, J., Hind, A., & Ryder, J. (2003). Designing and evaluating short teaching interventions about the epistemology of science in high school classrooms. *Science Education*, 87(6), 831–848
- Lederman, N. G. (2004). Syntax of nature of science within inquiry and science instruction. In L. B. Flick & N. G. Lederman (Eds.), *Science & technology education library: Vol. 25. Scientific inquiry and nature of science* (pp. 301–317). Dordrecht: Springer.
- Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education*. Mahwah, N.J: Lawrence Erlbaum Associates.

- Lederman, N. G., & Abd-El-Khalick, F. (1998). Avoiding de-natured science: activities that promote understandings of the nature of science. In W. F. McComas (Ed.), *The Nature of science in science education. Rationales and strategies* (pp. 83–126). Dordrecht: Kluwer Academic Publishers.
- Leibham, M. B., Alexander, J. M., & Johnson, K. E. (2013). Science interests in preschool boys and girls: Relations to later self-concept and science achievement. *Science Education*, 97(4), 574–593
- Lin, H.-s., & Chiu, H.-L. (2004). Student understanding of the nature of science and their problem-solving strategies. *International Journal of Science Education*, 26(1), 101–112
- Mason, L., & Bromme, R. (2010). Situating and relating epistemological beliefs into metacognition: studies on beliefs about knowledge and knowing. *Metacognition and Learning*, 5(1), 1–6
- McComas, W. F., & Olson, J. K. (1998). The nature of science in international science education standard documents. In W. F. McComas (Ed.), *The Nature of science in science education. Rationales and strategies* (pp. 41–52). Dordrecht: Kluwer Academic Publishers.
- Neumann, I. (2011). *Beyond physics content knowledge: Modeling competence regarding nature of scientific inquiry and nature of scientific knowledge*. Berlin: Logos.
- Neumann, K., Viering, T., Boone, W. J., & Fischer, H. E. (2013). Towards a learning progression of energy. *Journal of Research in Science Teaching*, 50(2), 162–188
- Papadouris, N., & Constantinou, C. P. (2011). A philosophically informed teaching proposal on the topic of energy for students aged 11–14. *Science & Education*, 20(10), 961–979
- Papadouris, N., & Constantinou, C. P. (2014). An Exploratory Investigation of 12-Year-Old Students' Ability to Appreciate Certain Aspects of the Nature of Science through a Specially Designed Approach in the Context of Energy. *International Journal of Science Education*, 36(5), 755–782
- Peters, E. E. (2012). Developing content knowledge in students through explicit teaching of the nature of science: Influences of goal setting and self-monitoring. *Science & Education*, 21(6), 881–898
- Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*, 26(4), 387–409
- Schwartz, R. S. (2013). *Impacts of explicit/reflective nature of science instruction in the context of an undergraduate biology course*. Paper presented at the NARST annual conference, Rio Grande, Puerto Rico.
- Schwartz, R. S., & Crawford, B. A. (2004). Authentic Scientific Inquiry as a Context for Teaching Nature of Science: Identifying Critical Elements for Success. In L. B. Flick & N. G. Lederman (Eds.), *Science & technology education library: Vol. 25. Scientific inquiry and nature of science* (pp. 331–355). Dordrecht: Springer.
- Solomon, J. (1991). Teaching about the nature of science in the british national curriculum. *Science Education*, 75(1), 95–103
- Songer, N. B., & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, 28(9), 761–784.
- Tsai, C.-C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education*, 82, 473–489.
- Urhahne, D., & Hopf, M. (2004). Epistemologische Überzeugungen in den Naturwissenschaften und ihre Zusammenhänge mit Motivation, Selbstkonzept und Lernstrategien [Epistemological beliefs in science and their relations with motivation, self-concept and learning strategies]. *Zeitschrift für Didaktik der Naturwissenschaften [German Journal of Science Education]*, 10, 71–87.
- Yang, F.-Y., & Tsai, C.-C. (2012). Personal epistemology and science learning: A review on empirical studies. In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 259–280). Dordrecht: Springer.